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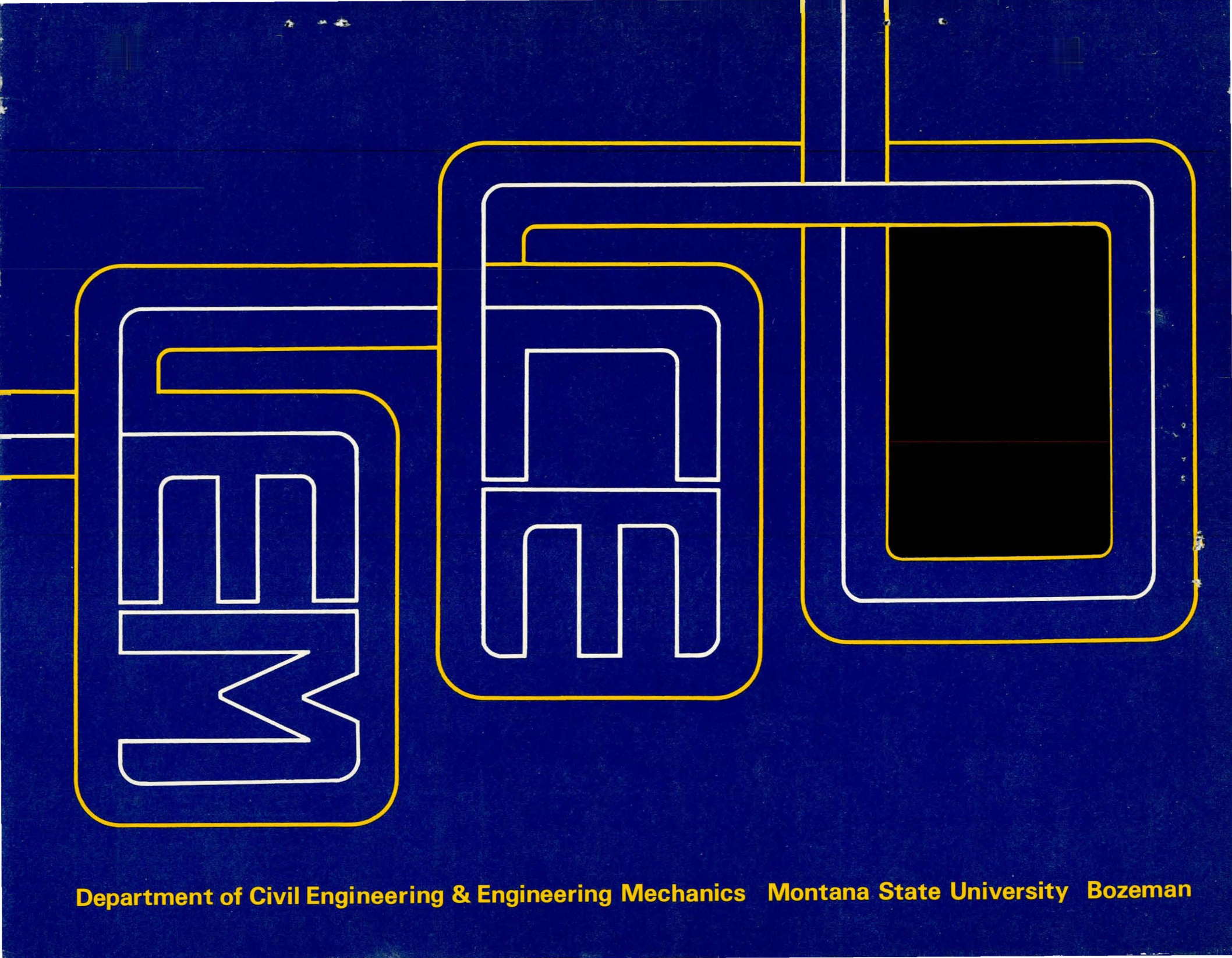
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EFFECTS OF MINE HAUL ROADS ON THE WATER RESOURCE

A FINAL REPORT

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by

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AUTHORIZATION

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This report is submitted to complete fulfillment of said Research Agreement.

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INTRODUCTION

Impacts on water resources by road construction, operation and maintenance are readily recognizable. Among these impacts are concentrated surface runoff, soil disturbance and loss, disruption of surface and groundwater flow patterns, and degradation of water quality. Effects of these impacts on land use, water supplies, wildlife and fisheries are obviously detrimental. Environmental awareness now dictates that these impacts and effects be scrutinized at the planning stage of road projects. Planners and designers are now faced with the problem of quantitatively predicting hydrologic impacts (i.e., how much sediment will a particular roadway design and location produce?) Effective, workable tools are needed to quantify these impacts.

Exploration and extraction of minerals, particularly coal, have increased tremendously in western United States, and promises to continue. Haul road systems for such surface mining activities may contribute more impacts to water resources than conventional roads. If a reliable simulation model was available to predict the hydrologic impacts of mine transportation systems, it would provide a valuable tool for planners and engineers of the mining industry and regulatory agencies.

With this in mind, SEAM (Surface Environment and Mining), U. S. Department of Agriculture, Forest Service, initiated studies with the ultimate objective of formulating model(s) that would quantify impacts from surface transportation systems. Initial work was begun by the Civil Engineering Department of Montana State University in 1974. The first year was used to broadly view and identify all impacts from transportation systems.(1)

The scope of the study was reduced to a more workable focus, haul roads and the water resource in June 1975. The term, water resource, included impacts associated with water quality (chemistry) and fugitive dust, as well as sedimentation. In July of 1976, an Interim Report was published. (2) This report summarized results of an extensive literature review and other information searches of subject material broadly related to roads and water degradation. In essence, it showed that the state of the art was rather limited concerning chemical water quality and fugitive dust. Sedimentation information was considerably more abundant, but applicable mostly to agricultural lands, not roads.

Therefore, the scope of the study was further refined and attention was centered on sediment modeling. Efforts in water quality were limited to maintaining vigilance in research by the California Department of Transportation. CALTRANS had initiated studies on the relationships between highways and water quality chemistry. During this time, the primary study effort was aimed at the Road Sediment (ROSED) Model developed by Simons and Li at Colorado State University. Preliminary study and testing of ROSED were begun and reported upon in a Progress Report, 1977. (3) Status of the California study and of other potential water quality resources were also given in that report. During the following year, the ROSED Model was manipulated and modified for use on the Sigma 7 computer of Montana State University. A Users Guide was published in 1978. (4)

It became apparent that verification of ROSED was not possible without reliable field data. Therefore, during the summer of 1978, several field tests were conducted on mine haul roads in Montana and Idaho. In a cooperative effort with Forest Service Laboratories in

Logan, Utah and Bozeman, rainulators were used to simulate rainfall on several haul road plots. Extensive runoff data, sediment production, and other related data were obtained for input into the ROSED Model. In addition, runoff and sediment yield data from natural storm events occurring on instrumented road sections in Oregon were evaluated for ROSED.

In the time period, fall 1978 to spring 1981, the data from the rainulator studies and Oregon plots have been processed and utilized to calibrate and test the ROSED model. The original date of project completion, October 1, 1979, was extended to allow digestion of the voluminous amount of data.

Thus, the primary objective of this final report is to describe, in detail, the rainulator studies, to summarize the data, and to give results of the calibration and testing of the ROSED Model. A portion of the rainulator data was tested by Ward and Li at Colorado State University to obtain an independent comparison of model manipulation. Their testing results are included in this report to further aid the reader in evaluating ROSED.

A secondary objective of this report is to give a recent overview of the state of the art of the chemical aspects of water quality as affected by roads. Efforts were limited to literature reviews and communications with the California Department of Transportation.

PART 1. ROAD SEDIMENT MODEL - ROSED

INTRODUCTION AND SELECTION OF MODEL

The evolutionary details of how the ROSED Model was selected as the predictor model to be tested are contained in references (2) and (3). This section is included only to provide continuity and a brief background to the reader of the potential models that were investigated.

The first model to be evaluated was the Universal Soil Loss Equation. The writings of Wischmeier (5,6,7), Foster (8), and Utah State Water Research Laboratory (9) were studied. Although Utah State had made inroads upon adapting the USLE for uses in road construction, it was felt that the method was basically agriculturally oriented.

A trail of studies of and/or discussions with Foster, Ports (10), Meyer (11), Howell (12), Poche (13), Sultan (14), Swerdon (15), Younkin (16), A. Miller (17), the Federal Highway Administration and others finally culminated at Colorado State University. At CSU, Simons and Li (18) were developing a road sediment model, ROSED. A physical process model, ROSED appeared to have an advantage to this study in that it could be applied to roads in general. That is, site specificity should not be a problem.

ROSED was developed from research in timber haul roads for the U. S. Forest Service; therefore, the model lends itself to a cooperative program of evaluation and testing. Simons, Li and Ward and other Colorado State University staff were and are eager to have ROSED tested by others. This state of cooperation by CSU and the Forest Service fit well with the objectives of the Montana State study. Thus in addition to its scientific feasibility, ROSED has had the added advantage that it could be tested in a fairly expeditious manner.

Simulated rainfall was used for several reasons: first, natural precipitation during the field season is infrequent and of short duration over much of the Northern Great Plains coal region; second, instrumentation of a number of road sections to await natural precipitation is expensive and risks loss of data through instrument malfunction. Therefore, a modified Colorado State University rainfall simulator (rainulator) was used to generate rainfall events on isolated sections of road. The following sections will detail these rainulator tests, summarize the data, and give an evaluation of the ROSED model. This report will also offer general suggestions for improved field techniques for rainulator studies and recommendations for future studies and modifications to the ROSED model.

DATA COLLECTION FOR MODEL

Within this chapter, the basis for collection of data is discussed. The question of what data is necessary is answered by giving the results of a rainfall simulator conference. This is followed by a description of the field rainulator apparatus and its application to field study sites.

Rainfall Simulator Conference

On June 19-20, 1978, a conference was held in Alamosa, Colorado, during which participants agreed upon data requirements for rainfall simulator studies. Eric Sundberg, representing Montana State, attended to assure that pending ROSED simulator studies would be adequately documented. Other agencies that attended included the Bureau of Land Management, U. S. Geological Survey, and the Southwest and Northwest Watershed Research Centers of the Science and Education Administration of the U. S. Department of Agriculture. The following is a summary of the data requirements set forth by the conference and outlined by Shiao (19).

Data Requirements

The Conference discussed the possibility of standardizing the data collection such as site selection procedures, and some of the physical characteristics of the site. The discussion is divided into five categories: (A) Dimensions of the plot, (B) Rainfall, (C) Runoff, (D) Soil and Sediment, and (E) Water quality.

A. Dimension of the plot. Plot sites varying from 65 to 72.6 feet have been used in the rainfall simulation study. The dimension of the plot is restricted by the watershed topography. Sometimes, it is not feasible or practical to select an area which has the desirable dimension. It is tentatively recommended that the minimum slope length of a plot is 60 feet. The differences in dimension and the arrangement of dikes or ditches and its slope may result in substantial difference in the time of concentration of the flow. However, the time of concentration of the flow is considered to be less important as comparing to peak discharge, total runoff volume, and shape of the hydrograph.

B. Rainfall. Subjects considered herein include intensity, the total amount of rainfall, and the number of rain gages and nozzles.

The total amount of rainfall is limited by the capacity of the water reservoir. The average rainfall intensity is about 2 in/hr for most of the study. The minimum number of nozzles is recommended to be 20. A simple way of estimating the number of rain gages is the number of nozzles. Variable rainfall intensity is suggested or planned for some of the future study. An automatic rainfall recorder has been used to record the rainfall. An automatic rainfall recorder has been used to record the rainfall; however, in most of the studies, the wedge-shape total rain gage was used.

C. Runoff. The major concern about runoff data is the length of record and sampling frequency. A recording gage was recommended to measure the runoff for all the simulator studies. The length of runoff record is recommended to last until the equilibrium condition is reached. However, it is limited, sometimes, to the soil condition especially in dry run and water availability. If water is a problem, it is suggested to run the study as long as possible. Dye is recommended to measure the velocity of the plot runoff at the stage of equilibrium. Deposition in the ditch or at the entrance of the flume may affect the gage height reading.

D. Soil and Sediment. This cateogry includes all physical characteristics related to soil and sediment. Soil moisture samples before each run are taken routinely in the USGS simulator studies to a depth of about 40 cm. Soil moisture profiles before and after each run, especially after each run, are recommended in aid of calibrating parameters in the Green and Ampt infiltration equation. However, no specific instrument is available to measure the moisture front. Studies are needed to look into the possibility of assembling a simple portable equipment to measure the moisture front. It was agreed to use the SCS system of soil descriptions. The BLM-SVIM system is recommended to describe the cover condition of the plot, especially in rangeland area.

Size distribution of soil from the source area should be sampled before each run. A minimum of 10 samples should be taken. The depth of the sample is about 10 cm. The composite soil consists of 10 samples or more and is used to determine the size distribution. A sample of the top 2 cm of soil should be obtained for comparison with sediment particle size analyses. Sediment yield samples collected during the run are analyzed to determine the size distribution of the transport materials. It is recommended

TABLE 1

Data	Recommendation or Criteria
Dimension of Plot	Slope length no less than 60 feet.
Rainfall	Intensity if about 2 in/hr. Number of nozzles is no less than 20. Number of rain gages is the same as nozzles.
Runoff	Measure with a stage recorder for 45 minutes. Sample at 1-minute intervals as long as possible or until equilibrium is reached.
Soil	Use SCS system for soil description. Use BLM-SVIM system for vegetative cover. Sample soil moisture before and after each run. Sample soil bulk density before the run. A minimum of 10 samples should be taken before the run for determining the size distribution of soil.
Sediment	Sample at 1-minute intervals at first 5 minutes. Sample at 3- or 5-minute intervals after the first 5 minutes. Analyze the size distribution of the transport material.
Water Quality	Obtain sample of applied water.

that the sediment sample should be taken at 1-minute intervals at the first 5 minutes of the run, if possible. The sampling frequency may be increased to 3- or 5-minute intervals after the first 5 minutes.

E. Water Quality. Water quality of the applied water is apparently an unimportant factor. Therefore, fewer data are available. Because run time is so short, the soil does not have enough time to respond. The quality of the recorded flow is about the same as that of the applied water. A sample of applied water may be obtained to determine unusual reactions.

Description of Rainulator

The modified CSU rainulator consists of a set of sprinkler heads on 11-foot (3.34 m) risers with sprinkler pressure controlled by a regulator at the base of each riser. This rainulator calibration by Neff (1979) (20) showed: (a) uniform areal distribution for plots up to 3000 ft^2 (279 m^2) at wind speeds less than 7 mi/hr (11.3 km/hr) and decreasing uniformly thereafter; (b) drop size less than natural rainfall of the same intensity; (c) kinetic energy about 40 percent of natural rainfall events.

Support equipment included a 5000-gallon (18.93 m^3) water storage bag, a 250-gallon.minute (0.95 m^3/min) pump, and a 2000-gallon (7.57 m^3) tank truck. Measurement equipment included a triangular, supercritical Replogel flume, a FW-1 stage recorder with 120-volt electric chart drive, recording rain gauge, nonrecording rain cans, nuclear density measurement instrument, a hot-wire anemometer, and water sample bottles.

Field Procedure for Use of Rainulator

Road sections for application of simulated rainfall were selected for uniformity of surface configuration, road gradient and surface materials. Each road section was considered a unique plot and no attempt was made to

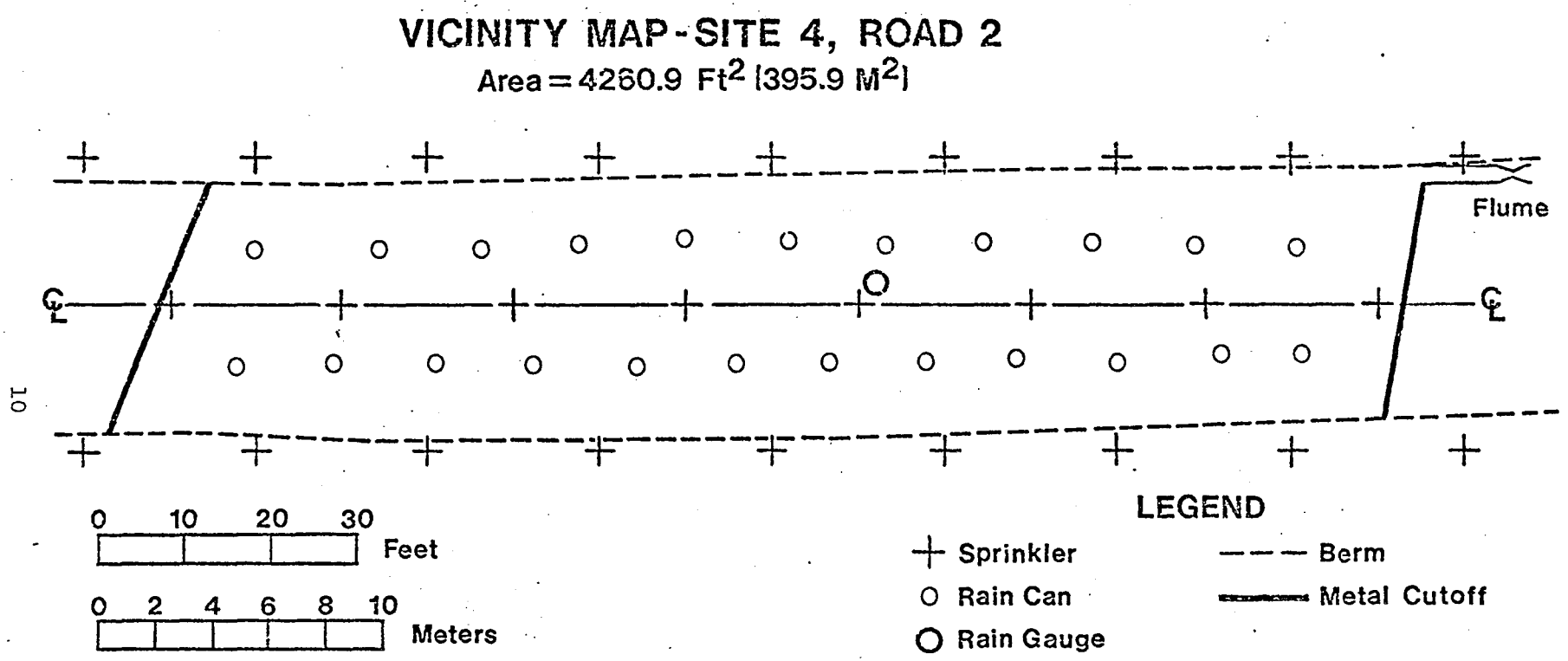

Fig. 1. Typical Rainulator Layout.

replicate plot conditions. Test sections were deliberately selected with a wide variety of length, width, and slope characteristics within the normal standards for mine road design and construction.

Sections with a ditch-to-ditch width of 34 ft (10.4 m) or less could be covered entirely by the rainulator system. Maximum effective coverage of 4420 ft^2 (0.1015 acre or 410.6 m^2) could be attained by using 24 sprinklers in three parallel rows 17 ft (5.2 m) apart, each with eight sprinklers at 20 ft (6.1 m) spacings. Adjacent rows were shifted 10 ft (3.05 m) to create a staggered effect for more uniform coverage. Half widths of wider roads were used by having the mining company grade a berm along the road crown, then setting the rainulator over the berm-to-ditch width. Figure 1 shows a typical rainulator layout.

Each selected road section was isolated by excavating a shallow ditch and installing metal cutoff walls across the upper and lower ends of the section. Side borders were provided by the earth berms normally constructed on the sides of mine roads in compliance with safety regulations. A chemical soil stabilizer was sprayed on the ditch-berm perimeter to prevent extraneous sediment contribution from these areas. A metal trough was placed to collect and convey water from the lowest corner of the road section to the flume.

The recording rain gauge and supplementary rain cans were located in a grid upon the road section to measure rainfall distribution. Soil was scraped from the first centimeter of the road surface at random locations to accumulate a 5- to 10-pound (2.2 to 4.5 kg) composite sample. In addition, loose soil on the road surface was measured by sweeping and collecting the soil from within a 4-ft^2 (0.37 m^2) area enclosed by a metal ring 2.26 ft (0.69 m) in diameter. These samples were taken before and after rainfall

application at several random locations across the section. Bulk density measurements were made (nuclear equipment) and soil moisture samples were collected before and after each rainfall application.

Reference pins 10 ft (3.05 m) apart and aligned in the expected direction of overland flow were placed at various locations on the road section. The velocity of overland flow at these locations was measured periodically during rainfall application by placing a small mass of dye upslope from each 10-ft spacing and timing the passage of the center of mass between the pins. The time each test was performed was noted so that these dye travel measurements could be related to the runoff hydrograph.

Water was applied at a uniform rate of approximately 2 in/hr (5.1 cm/hr) for at least thirty minutes, usually during the early morning when the air was relatively calm. Tests were suspended when wind gusts exceeded five mi/hr (8.05 km/hr). Field data included the times of beginning of rainfall, detention storage, overland flow, entry of runoff into the flume, and times when rainfall and runoff stopped. One-liter water samples were collected at the flume outlet at 1-min intervals during the rising stage and at 2-min intervals from the peak runoff through the recession limb of the hydrograph.

Rainfall was applied until runoff stabilized or until the water supply was exhausted. After rainfall stopped, the catch in the rain cans was measured and compared with the rain gauge record to evaluate uniformity of coverage. If a second run with the road in a prewetted condition was desired, then the procedure was repeated the following day or during the same day if wind conditions allowed. After all runs on a road section were completed, a tape and level survey was made to map the location to the nearest 0.1 ft (3 cm) and elevation to the nearest 0.01 ft (0.3 cm) of plot

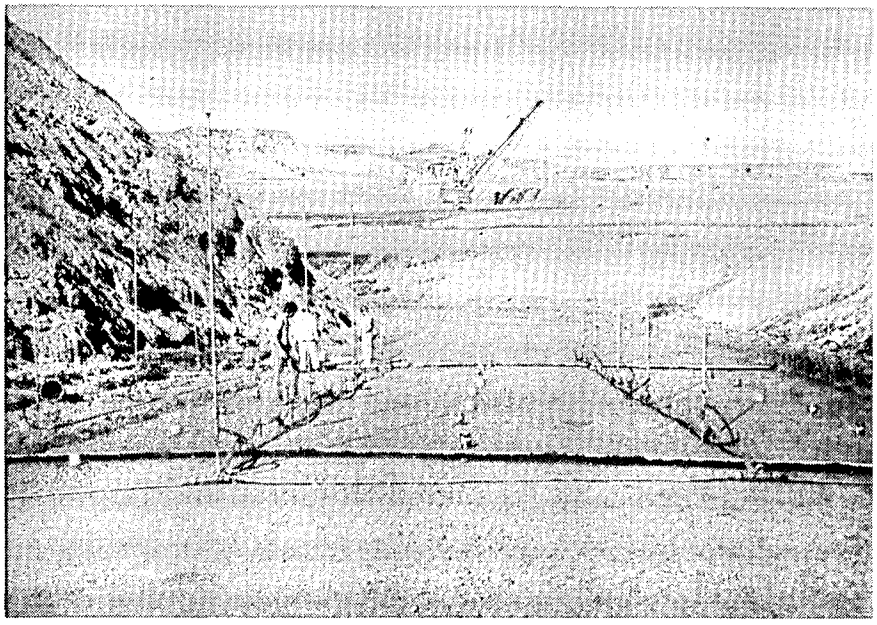

Fig. 2. Setting Rainulator System on Coal Mine Haul Road.

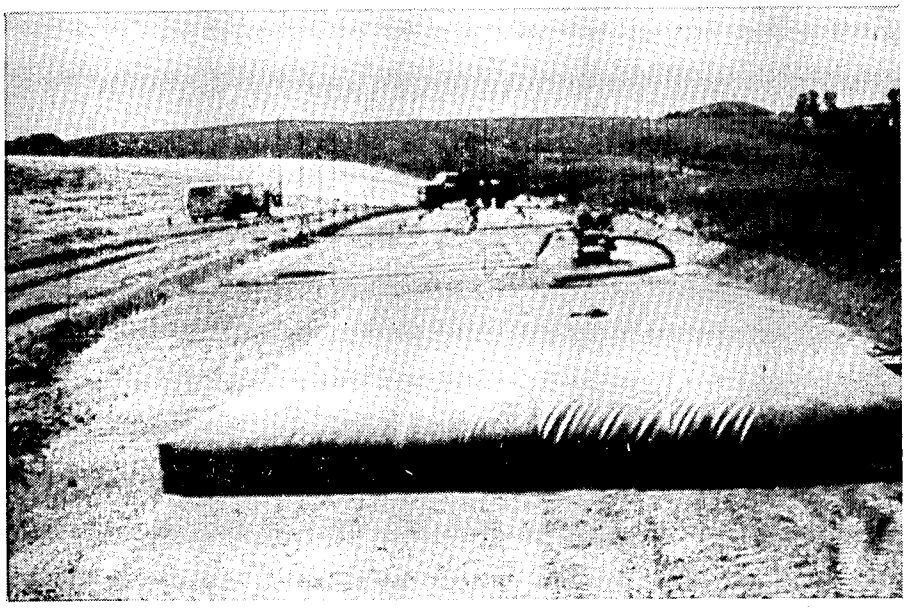

Fig. 3. Rainulator in Background. 5000 gal. Water Storage Bag and 250 gal. Per Min. Pump in Foreground.

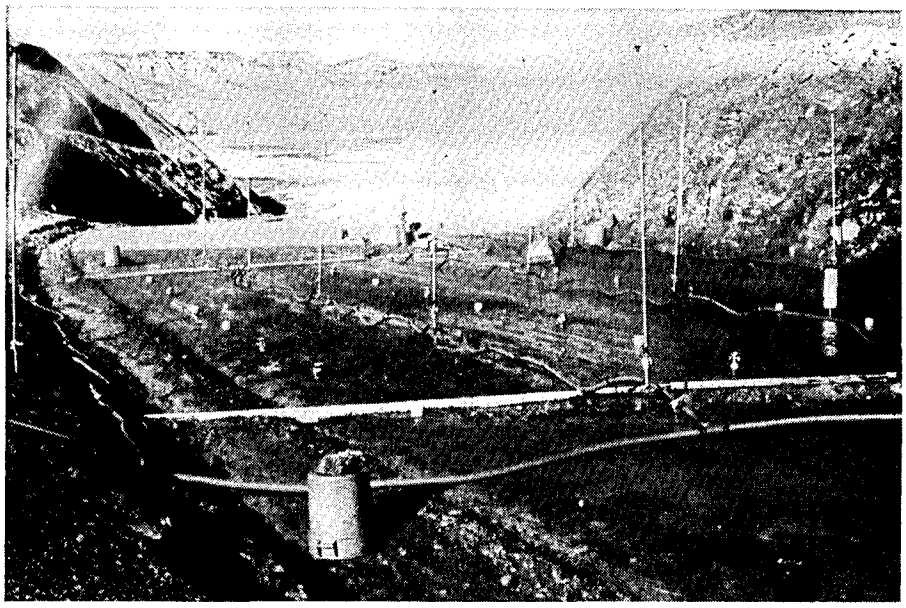

Fig. 4. Rainulator in Operation With Longitudinal Overland Flow in Initial Stage.

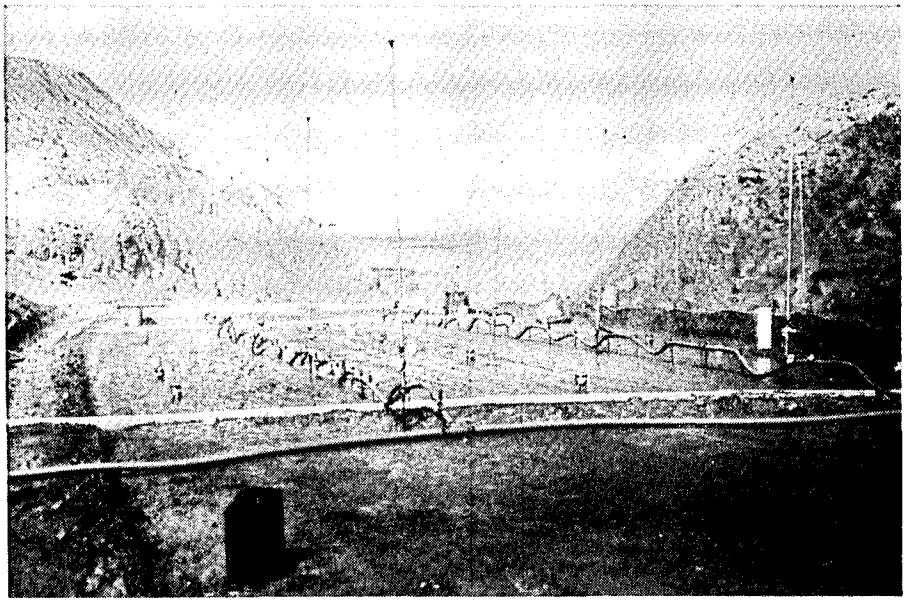

Fig. 5. Rainulator Operation With Longitudinal Overland Flow in Advanced Stage.

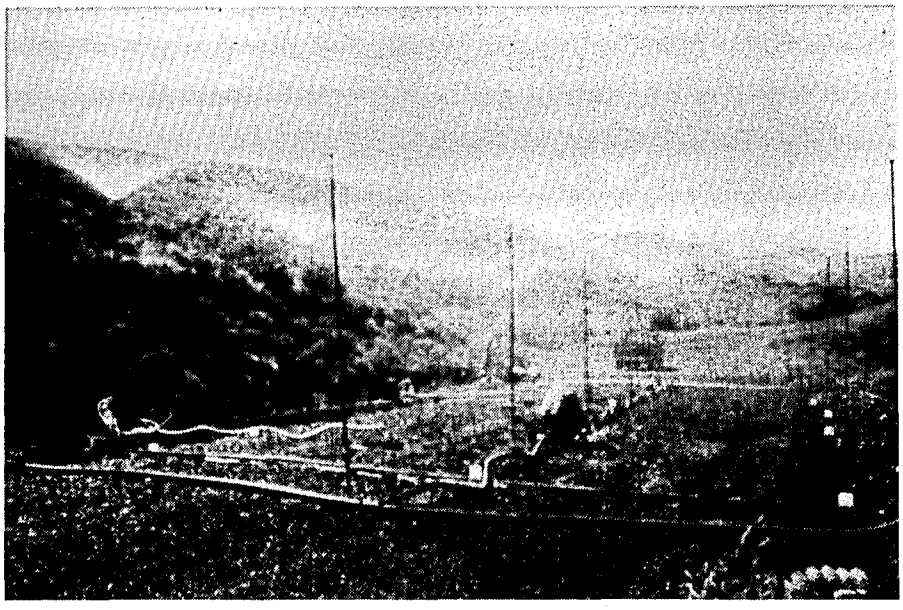

Fig. 6. Rainulator Operation Showing Sprinkler Coverage.

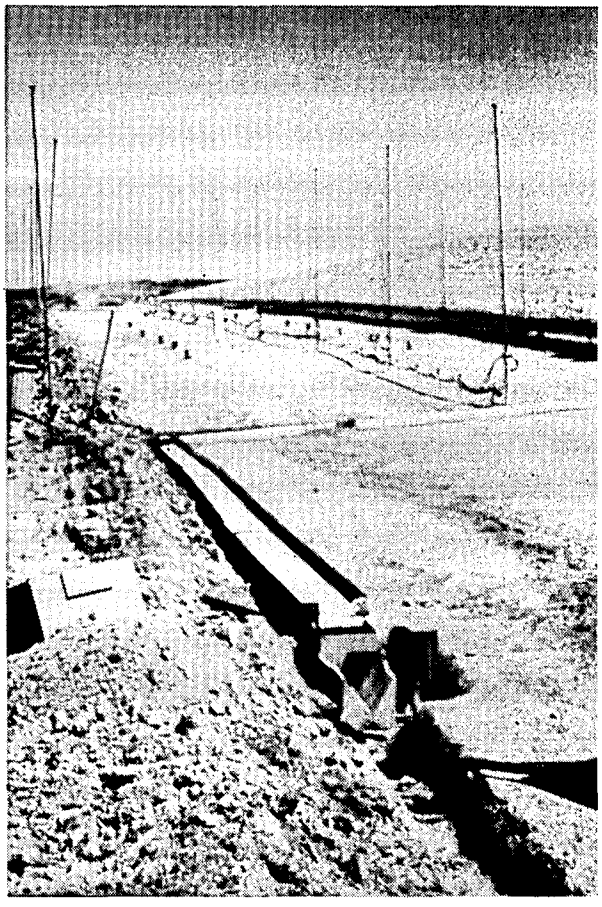

Fig. 7. Rainulator With Runoff Collector Trough and Flume in Foreground.

boundaries, sprinklers, rain gauge, and rain cans (see figure 1).

A motion picture camera set for a time lapse mode was used to photograph each plot during simulated rainfall. These films provided graphic evidence of the timing of runoff from portions of the plot and provided clues to accurate modeling of response units and the routing sequence.

Figures 2-7 show a sequence of photographs of the rainulator and support equipment.

DOCUMENTATION AND ANALYSIS OF RAINULATOR DATA

The major types of field data to be discussed in this section include: surveys of rainulator plots, soils testing, rainfall intensity and duration, rainfall distribution, runoff hydrographs, and sediment yield characteristics. A standardized format is used for presentation of each data type. A description is made of the analysis procedure for each data type and examples of the results are illustrated. The total package of summarized data needed for the ROSED input parameters are available in computerized format, but are not included herein.

The large amount of data generated by the rainfall simulator tests required a heavy reliance on computer digitizing of survey data, rainfall data, observed hydrographs and measured sediment yield. Several data management programs were written to expedite data analysis. Special computer graphics programs were developed for direct display and comparison of observed hydrographs and sedimentgraphs with predictions. These programs greatly improved the ability to rapidly evaluate the quality of field data and the accuracy of ROSED results. Outlines of the programs and computer graphics are included in this report.

Plot Surveys

Each selected road section was surveyed utilizing offsets from a

```
**********************
*                    *
* DATA PREPARATION   *
* CONTOUR DISPLAYS   *
*                    *
**********************

SAVAGE ROAD 1
FILE: ST51G

      MINIMUM     MAXIMUM
X:  .0000E+00   .1200E+03
Y:  .7000E+02   .1300E+03
Z:  .9600E+02   .1000E+03

GRID SIZE:   .1500E+02
CONTOUR
INTERVAL:    .2500E+00

PLOTTER COPY (Y/N) ?
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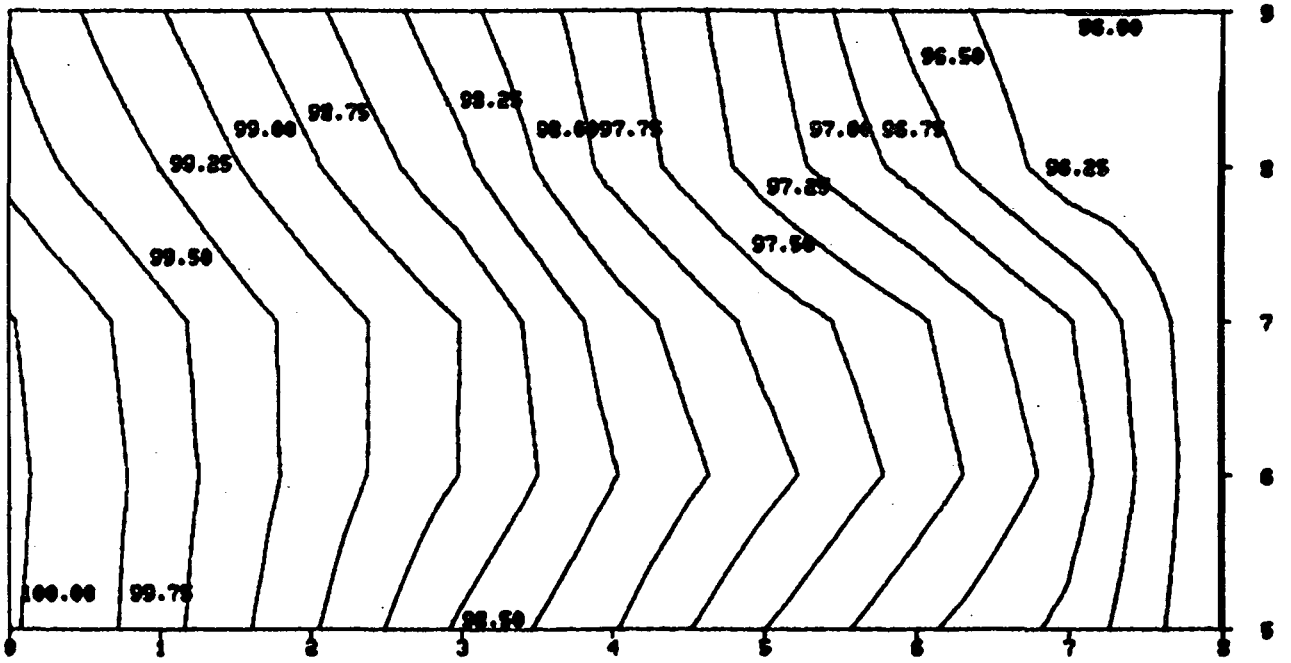


Fig. 8. Typical Contour Map of Rainulator Plot.

convenient baseline. Major features were located in reference to the baseline and elevations were recorded to the nearest 0.01 ft. Plot vicinity maps were developed from the field notes (fig. 1) and cross sections of the road were drawn for each centerline station. The vicinity maps and cross-sections were then digitized on the minicomputer system to develop contour maps for the plots (fig. 8). Plot areas were determined by digitizing the vicinity maps.

Plot geometry data are a direct input for the ROSED model. Needed parameters are plot length, slope of plot, ditch length, slope of ditch and the sideslope of ditch.

Soils Testing

A number of soil parameters are needed for the simulator work with ROSED. The measured parameters for each soil include soil gradation, antecedent and post storm soil water content, particle specific gravity, and soil bulk density.

Surface soil samples were collected at random locations on the plots by two methods. The first method consisted of scraping a thin layer of the road surfacing from areas large enough to supply 5-10 pounds of soil. Samples of this type were collected before and after rainfall simulations. The second method consisted of sweeping the soil surface with a stiff broom to obtain loose soil storage from the aforementioned metal ring enclosures. All soil samples were placed in sealed containers and shipped to the laboratories at Montana State University.

Classification of Soils

In Bozeman, the samples were weighed, dried, and given a classification analysis according to ASTM procedures. Gradation analysis of all samples included dry and wet sieving plus hydrometer tests. These tests resulted in

TABLE 2

Composite Gradation Curve Values For The Road Sites.

(Values are geometric means of diameter in mm for each size class)

Proportion in Diameter Class	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
Site 1 Road 1	8.23	5.99	4.02	2.56	1.37	.552	.164	.058	.0234	.00177
Site 2 Road 1	8.226	6.19	4.65	3.35	2.245	1.13	.43	.123	.025	.0016
Site 2 Road 2	8.166	6.03	4.45	3.08	1.94	1.00	.417	.114	.0213	.0015
Site 3 Road 1	7.11	3.85	1.70	.732	.382	.212	.115	.062	.0274	.00196
Site 3 Road 2	6.55	2.85	1.04	.433	.261	.193	.129	.063	.0179	.00139
Site 4 Road 1	7.37	4.20	2.23	1.04	.441	.202	.103	.048	.011	.00098
Site 4 Road 2	6.90	3.32	1.28	.430	.163	.081	.04	.015	.0046	.00077
Site 5 Road 1	10.14	6.99	5.03	3.01	1.19	.414	.177	.057	.011	.001
Site 5 Road 2	10.27	6.44	3.97	2.53	1.35	.569	.1576	.0574	.0097	.0011
Site 5 Road 3	10.71	7.42	4.95	2.69	1.19	.487	.198	.073	.024	.0018

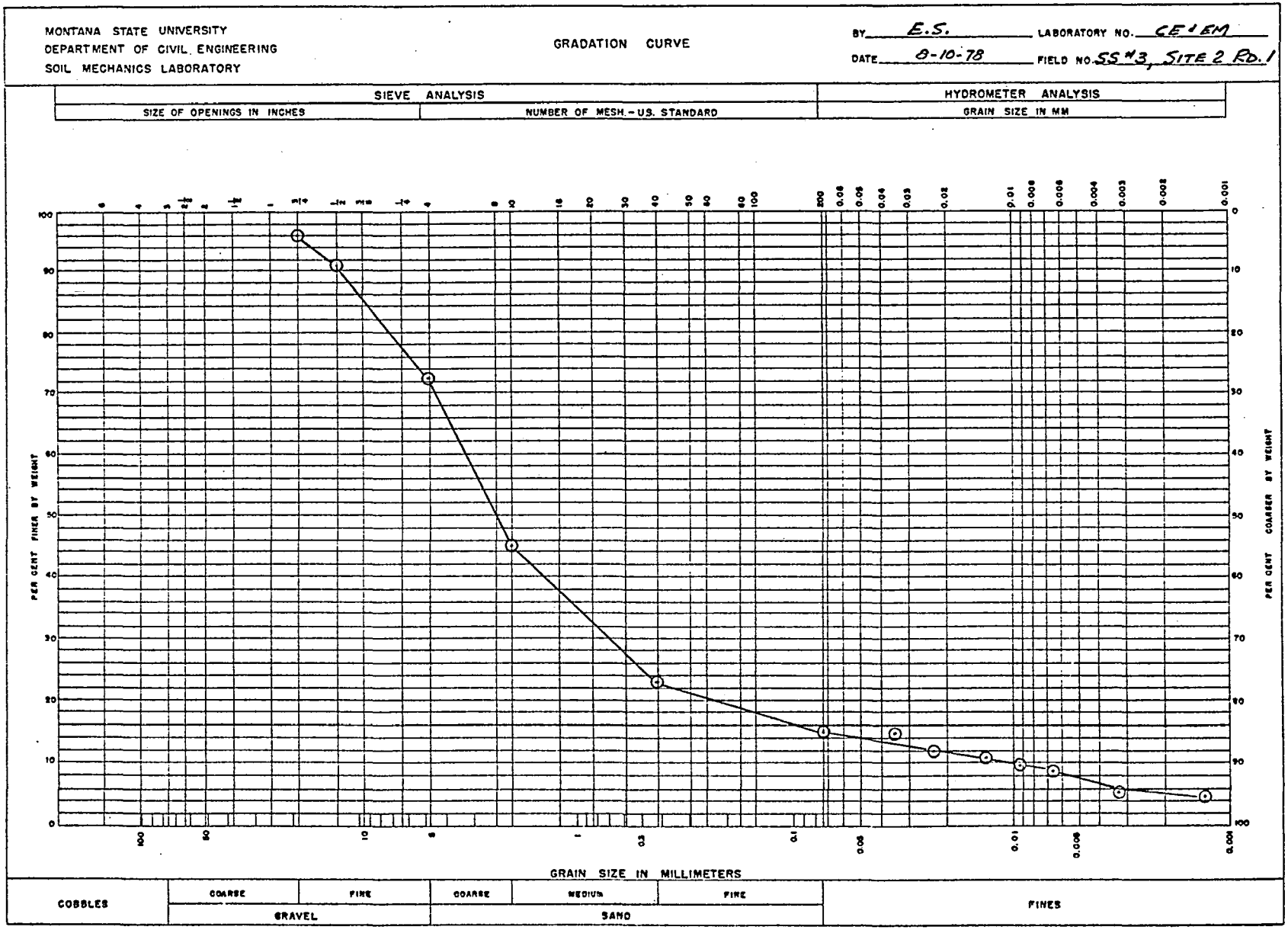


Fig. 9 . Gradation Curve of Soil From Road Surface.

the development of a gradation curve for each of the soil samples (fig. 9). Included in these analysis were tests to develop a Plasticity Index and liquid limits for the soils. Measurements of particle density or specific gravity were accomplished with an air pycnometer. Gradation curves for each road location were then composited to develop a single gradation for that site. Table 2 presents these composite gradation data.

Density Tests

Surface soil bulk density was measured on each plot with a Campbell-Pacific surface nuclear gauge. This device measures the absorption rate of gamma radiation by the soil to determine the density. Corrections for soil water content are made by measurements of high speed neutron attenuation rate with the same device (21). The surface bulk density results are summarized in Table 3.

Soil Water Content

Soil water content data were available from two sources. The first source was the neutron scattering measurements obtained from the nuclear surface density gauge. The second source was from gravimetric samples which were collected from several locations on the plot surface immediately before and after each rainfall simulation. These samples were given routine laboratory testing to determine water content on a dry weight basis. Results of these analysis are presented in Table 4. Due to the highly compacted nature of the plot surfaces, the gravimetric water contents are actually representative of the soil surface material.

Table 3. Surface Bulk Density

Site ID	Road Number	Average Surface Bulk Density gm/cm^3
1	1	1.90
2	1	1.87
	2	1.85
3	1	1.65
	2	1.69
4	1	1.67
	2	1.67
5	1	1.95
	2	1.92
	3	1.96

Rainfall Applications

A series of measurements were made to characterize the water applications to the plots. These measurements were designed to determine rainfall distribution, total rainfall applied, and rainfall intensity.

Rainfall distribution

Rainfall distributions were measured by utilizing the randomly placed catch cans. The location of each of these cans had been referenced during the plot survey. Immediately following each simulation, the volume of water in each can was measured and recorded. These water volumes were later corrected to obtain a rainfall depth for each can location. Three methods were used for evaluating the spatial distribution of the rain. These were a) an arithmetic mean of the catch, (b) the use of Thiessen polygons, and c) isohyets which were drawn with computer graphics. After evaluation of these three methods it was determined that the arithmetic mean gave reliable results for all of the plots and saved a considerable amount of analysis time.

Rainfall Intensity

Rainfall intensity data were determined by two methods. In the first method, the total depth of rainfall was divided by rainfall duration in minutes to produce an average intensity per minute. The second method of

TABLE 4

Antecedent and Post-Soil Water Contents (Dry Weight Basis)

Site ID	Road	Run	Antecedent Soilwater Content θg	Post Simulation Water Content θg
1	1	A	.078	.108
		B	.108	.117
		C	.117	.128
2	1	A	.076	.117
		B	.117	.133
	2	A	.093	.138
		B	.138	.143
3	1	A	.024	.212
		B	.212	.245
		C	.245	.264
	2	A	.024	.166
		B	.166	.183
		C	.183	.185
4	1	A	.015	.219
		B	.219	.230
	2	A	.020	.263
		B	.263	.273
5	1	A	.013	.178
		B	.178	.197
	2	A	.015	.181
		B	.028	.149
		C	.149	.157
	3	A	.030	.129
		B	.129	.151

Table 5. Rainfall Intensity Duration Data.

(One Minute Intensity in Inches/Hr)

Site 1 Road 1 Run A Rainfall duration 12 min. Runoff duration 22 min.

1.15 1.15 1.15 1.15 1.15 1.15 1.15 1.15 1.15 1.15 1.15 1.15

Site 2 Road 2 Run B Rain duration 18 min Runoff 37 min.

1.80 1.80 1.80 1.80 1.80 1.80 1.80 1.80 1.80 1.80 1.80 1.80

Site 3 Road 1 Run A Rain duration 11 Runoff 17

2.1, 2.12, 2.05, 2.13, 2.35, 2.44, 2.86, 2.78, 2.27, 2.63, 2.06

Site 3 Road 1 Run B Rain duration 10 Runoff 19

1.16, 1.62, 2.09, 2.20, 2.02, 2.12, 2.32, 2.39, 1.88, 2.35

Site 3 Road 2 Run A Rain duration 13 Runoff 23

1.4, 1.84, 1.93, 1.94, 1.94, 2.15, 1.92, 1.99, 2.12, 2.05, 2.04, 1.80

Site 3 Road 2 Run C Rain duration 20 Runoff 28

1.64, 1.58, 2.06, 1.91, 1.75, 1.81, 1.85, 1.94, 1.95, 2.00, 1.93, 2.08,

2.08, 1.98, 1.61, 1.58, 1.78, 2.03, 2.02, 1.90, 1.82

Site 4 Road 1 Run A Rain duration 14 Runoff 21

0.94, 1.21, 1.46, 2.01, 1.63, 1.63, 1.73, 1.73, 1.61, 1.73, 1.66, 1.62,

1.42, 2.03

Site 4 Road 2 Run A Rain duration 12 Runoff 21

2.142, 2.142, 2.142, 2.142, 2.142, 2.142, 2.142, 2.142, 2.142, 2.142

Site 4 Road 2 Run B Rain duration 21 Runoff 39

1.68, 1.87, 1.93, 2.18, 1.90, 2.04, 1.91, 2.08, 2.06, 2.20 2.17, 2.11,

2.43, 2.13, 2.10, 2.20, 2.13, 2.20, 2.26, 2.14, 1.74

Site 5, Road 1 Run B Rain duration 34 Runoff 54

1.92, 2.06, 1.90, 1.45, 0.00, 1.88, 2.12, 1.94, 2.33, 2.14, 2.23, 2.30, 2.40, 2.13, 2.13, 2.11, 2.02, 1.95, 2.27, 1.82, 1.90, 1.82, 2.29, 2.11, 2.26, 2.01, 2.03, 2.24, 2.14, 1.91, 1.94, 1.81, 2.12, 2.09

Site 5 Road 3 Run C Rain duration 37 Runoff 50

1.59, 1.45, 1.83, 1.81, 2.01, 1.95, 1.99, 1.70, 2.03, 1.89, 1.58, 1.60, 1.54, 1.40, 1.71, 1.79, 1.94, 2.03, 1.70, 1.77, 1.75, 1.99, 2.04, 1.91, 2.06, 2.04, 1.80, 1.59, 2.05, 1.93, 1.72, 2.03, 1.65, 1.72, 1.90, 1.84, 1.85.

measurement was with a tipping bucket rain gauge. The tipping bucket mechanism was connected to a Rustrac event recorder. The recorder charts were later digitized to obtain a rainfall intensity in inches per hour at 1-minute intervals. The total catch and intensity data for the tipping bucket were adjusted in accordance with the average rainfall depth for the simulations. (Table 5). Variations in intensity data are due to wind effects and, in some cases, irregularities in the chart drive speed.

Runoff Hydrographs

Runoff hydrographs from the plots were digitized and files of runoff rates (in ft^3/sec and area-inches/min) and cumulative runoff in ft^3 were created for graphics display. In this manner, graphical comparisons of the plot results and ROSED predictions can be obtained. The digitizer produced a file for each hydrograph which consists of an average stage value for a pre-selected time interval (0.5 minutes for these charts). This file was then linked to a program which contains the rating curve for the small replogle flume. The program produces files which contain runoff rates in ft^3/time at specified 1-minute time intervals. Fig. 10 presents an example of actual rainfall vs runoff produced. The balance of these examples are presented in appendix.

Sediment Yield

During each rainfall simulation, total sediment samples were collected in one-liter bottles at one minute intervals from the start of runoff to the steady state or plateau of the hydrograph. Then samples were collected at 2-minute intervals until the end of runoff. In the laboratory, each sample was filtered with Millipore equipment to determine the weight of sediment per liter of water (gm/cm^3). These values were then converted to sediment concentration in lbs/ft^3 and plotted for digitizing at 1-minute

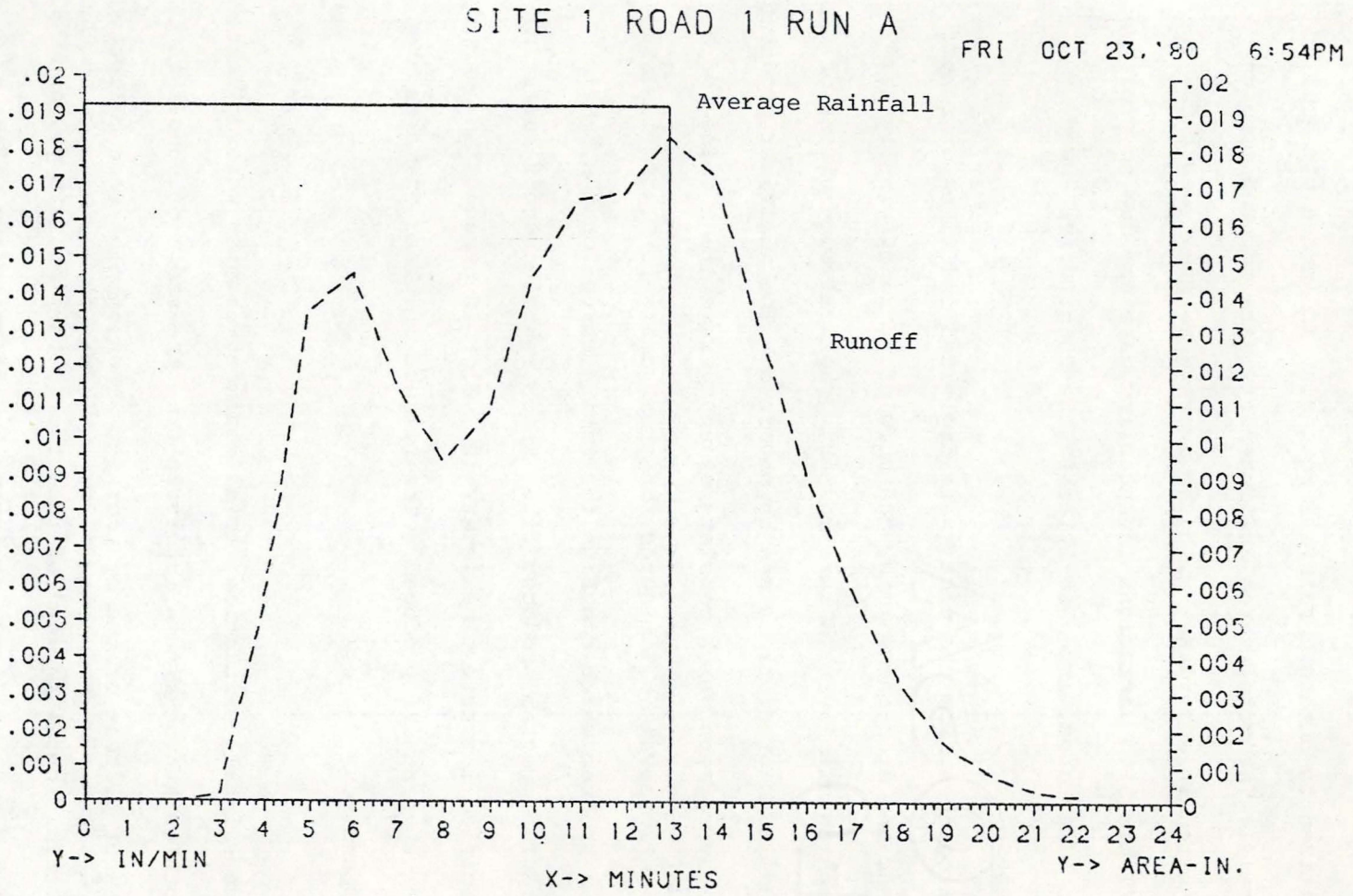


Fig. 10. Comparison of Applied Rainfall Intensity with Measured Runoff.

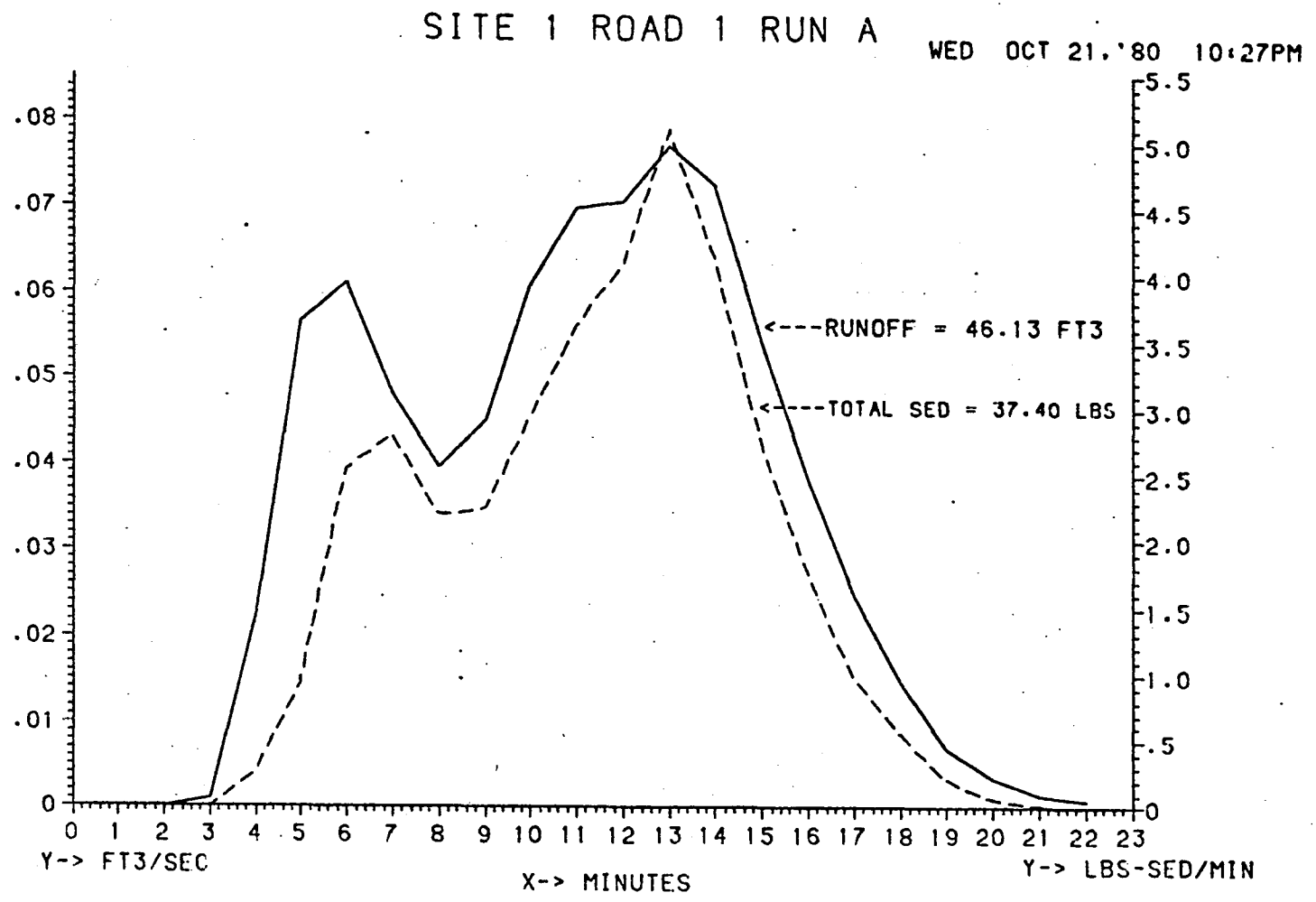


Fig. 11. Measured Runoff and Measured Sediment Yield from Applied Rainfall.

intervals. The 1-minute sediment concentration values were then multiplied by the water discharge for the respective time intervals to produce sediment yield in (lbs/min).

$$\text{Sediment yield } \left(\frac{\text{lbs}}{\text{min}}\right) = \text{sediment concentration } \left(\frac{\text{lbs}}{\text{ft}^3}\right) \times \text{discharge} \left(\frac{\text{ft}^3}{\text{min}}\right)$$

The sediment yield data was then plotted and digitized to create files for graphical comparisons and analysis (fig. 11). Sediment was saved from these samples for gravimetric particle size analysis. Gradation curves of the sediment were developed for each run (fig. 9).

Appendix presents the data in graphical format from all of the road sections which were studied. The data is presented in the finalized format that is needed for the ROSED model for each of the 24 rainfall simulations conducted for this study. The following section will outline the procedure needed to establish these parameters and identify the variables by their Fortran names.

DESCRIPTION AND OPERATION OF ROSED MODEL

The ROSED time-space water and sediment routing procedure uses a conceptual road prism with five response units: cut slope, fill slope, road surface, ditch, and culvert. Three types of flow are considered: overland flow, ditch flow, and culvert flow. In this study, only road surfaces and ditches which involve only overland flow and ditch flow were considered. The ROSED model used in this study produces two distinct but interconnected outputs: (1) a hydrograph by estimating rainfall excess, overland flow routing, and ditch flow routing, and (2) a sedimentgraph by estimating soil detachment by rainfall, soil detachment by overland flow, overland flow sediment routing, soil detachment by ditch flow, and ditch flow sediment routing. All these processes of detachment, transport, and storage are modeled by incremental time units.

This portion of the report outlines the ROSED model, and gives the reader the operational computer sequence utilizing the Fortran language. The intent is to assist the potential ROSED user in preparing his/her data for use in the model and to explain the input parameters used in this report. For derivation of the equations used to operate the model, the reader is directed to Simons, et al (ref.18).

Data Input Cards

The following lettering system identifies the sequence of data input cards for the ROSED model.

A. Title Card - Name of the data set. Format (10A7)

B. This card establishes general properties of the plot: NOV- number of overland flow response units, NDITCH-number of ditch flow response units, NCULVT-number of culvert flow response units, NDX-number of space increments (the number of subunits each response unit is divided into for routing calculations), NSTOM-number of storms, IMAX-maximum number of iterations (limits number of iterations possible to achieve convergence of algorithms), MM-number of soil particle size fractions. Format (7I10) Typical values selected for these fortran variables in this study are:

NOV - varies dependent on plot geometry

NDITCH- " " " " "

NCULVT_ " " " " "

NDX-5 (may want more for long continuous strips)

NSTOM-1

IMAX - 50

MM _ 10

C. General Information Card - This card contains the variables: EPS - convergence criterion (accuracy requirement for iterative process if IMAX < 50), DT - Time increment in minutes (number of minutes per time step in the simulation), SNV - kinematic viscosity of water in ft^2/sec. Format (2F10.3, 1E10.3)

Values selected for these values for the rainfall simulations are:

EPS - 0.01

DT - 1.00 minutes

SNV - 1.054E-05 ft^2/sec

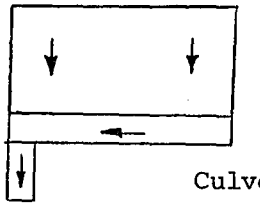
D. Computational Sequence Cards - one card is submitted for each flow response unit. These cards establish an integer matrix that describes the routing sequence for the flow response units and the type of flow (overland, ditch, or culvert) for each of the units. ISEG(I) - index of computational order, IUP (I)- index of upstream response unit (up to 3 upstream units are allowed per response unit), ILAT(I)-index of lateral response units (maximum per response unit is 2), ITYP(I)- index of flow type of the response unit (1 = overland, 2 = ditch, 3 = culvert).

Format (7I10)

Examples of these matrices are as follows:

ISEG(I)	IUP1	IUP 2	IUP 3	ILAT1	ILAT 2	ITYP
1	0	0	0	0	0	1
2	0	0	0	1	0	2
3	2	0	0	0	0	3

where:



Overland flow unit 1 = ISEG(1)

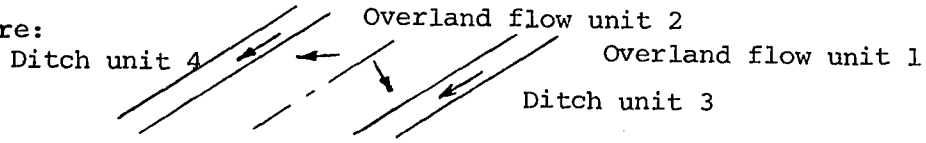
Ditch = ISEG(2)

Culvert = ISEG(3)

A more complex example might be

ISEG(I)	IUP 1	IUP 2	IUP 3	ILAT 1	ILAT 2	ITYP
1	0	0	0	0	0	1
2	0	0	0	0	0	1
3	0	0	0	1	0	2
4	0	0	0	2	0	2

where:



Needless to say, with this computational sequence very complex flow geometry can be routed in the ROSED model. The complexity or detail is a user option and will probably depend on the quality of the data that is to be tested with the model or the accuracy requirements of the test.

E. Basin Characteristics and Geometry Data Cards. One card is required for each flow response unit. The variable names are: IDSEG(I)-name of the response unit, SLEN(I)-length of the unit in ft, SLOP(I)-gradient of the unit $\frac{0/0}{100}$, PERM(I)-soil water hydraulic conductivity in the wetted zone in inches/hr, ALPHA(I)-average soil water suction head in the wetted zone in inches, GC(I)-ground cover denisty $\frac{0/0}{100}$, CN(I)-canopy cover density $\frac{0/0}{100}$, PMC(I)-soil moisture content in the wetted zone $\frac{0/0}{100}$, AMC(I)-antecedent soil moisture content $\frac{0/0}{100}$. Format (2X, A8, 8F8.3)

The response unit identification must correspond to the computational sequence cards to give the correct characteristics for the

plot. The variable IDSEG(I) is the key to the maintenance of this sequence. The value of the variables SLEN(I) and SLOP(I) can be determined from field survey data or topographic maps.

The procedure adopted for estimating the hydraulic conductivity - PERMI(I)-for the plots is as follows:

$$K_w = I - RO_p$$

where:

K_w = hydraulic conductivity in the wetted zone (PERM(I)) in $\frac{\text{inches}}{\text{hr}}$

I = rainfall intensity in $\frac{\text{inches}}{\text{hr}}$

RO_p = peak runoff rate in $\frac{\text{area-inches}}{\text{hr}}$

The average suction head in the wetted zone (ALPHA(I)) can be estimated with the following procedure: (18)

First, $\alpha = t_p\ (I)\ (\frac{I}{K_w}\ \ 1.0)$

where: α = a grouping of soil parameters

t_p = time to ponding or detention storage from beginning of rainfall in hours

I = rainfall intensity in $\frac{\text{inches}}{\text{hour}}$

K_w = hydraulic conductivity (PERM(I))

Next

$$e = G\ (\frac{\gamma_w}{\gamma_s}) - 1$$

where: e = soil void ratio

G = bulk specific gravity of soil particles

γ_w = density of water (1.0 gm/cm^3)

γ_s = bulk density of soil (gm/cm^3)

then

$$n = \frac{e}{1+e}$$

where: n = soil porosity ratio

next

$$S_i = \frac{W_i G}{e}$$

and

$$S_w = \frac{W_w G}{e}$$

where:

S_i = Initial degree of saturation of soil

S_w = degree of saturation of soil after wetting

W_i = Initial water content of soil

W_w = water content of soil after wetting

finally

$$\psi = \frac{\alpha}{(S_w - S_i)\phi}$$

where: ϕ = n or the soil porosity ratio

Ground cover density - GC(I) and canopy cover density - CN(I) were set at 0.0 in all tests of the simulator data. Final soil moisture content data PMC(I) and antecedent soil moisture contents AMC(I) were available from field gravimetric samples and the nuclear gauge readings for all simulations.

F. Basin Characteristics and Geometry Data Card, one card required for the entire plot. The input variable names on this card are: Z - side slope of ditch Z:1 horizontal-to-vertical in ft., DIA - diameter of culvert in feet, DEMAX - maximum depth of ditch in ft, GCI - volume of water intercepted by ground cover in inches, and CNI - potential volume of water intercepted by canopy cover in inches. Format (5F10.3)

The values used for Z varied from plot to plot depending on the configuration of the ditch at each specific site. For all of the simulator tests the following values were selected for the rest of the variables:

DIA = 1.0 ft

DEMAX = 0.5 ft

GCI = 0.01 in

CNI = 0.00 in

G. Flow Resistance Parameter Card - one card is used. The variable names are: FKL - which is the grain resistance parameter, and COEFN - which is the flow resistance coefficient for culverts. Format (2F10.3) The following values were assigned to the variables:

FKL = 50.0

COEFN = 0.025

H. Flow Resistance Parameter Cards - one card is used for each of the flow response units. The variables listed are: Al(I)-Coefficient for the wetted perimeter flow area relationship, Bl(I)-exponent for the wetted perimeter flow area equation, OFL(I)-the total flow resistance for sparse vegetation where GC(I) = 0.0, and OFH(I)-the total flow resistance for dense vegetation GC(I) = 1.0.

For overland flow situations Al(I) = 1.0 and Bl(I) = 0.0. For ditch flow the following equations are available:

$$Al(I) = \frac{(1+Z_1^2)^{1/2} + (1+Z_2^2)^{1/2}}{\left(\frac{Z_1 + Z_2}{2}\right)^{1/2}} \quad \text{when } Z_1 \neq Z_2$$

or

$$Al(I) = 2\,(Z_1 + {}^1/_{Z_1})^{1/2} \quad \text{when } Z_1 = Z_2$$

where: Z_1 and Z_2 = side slopes of the ditch Horizontal: Vertical in ft H/V

Bl(I) is 0.5 for ditch flow units. For this study OFL(I) and OFH(I) were set at 400.0 and 500.0 respectively. If a culvert or pipe is present the user is referred to Simons, et al, (21,22) for the appropriate values for Al(I) and Bl(I).

I. Size Distribution Cards - one card for each response unit. The variable entered on these cards is: DNB(I)- soil particle size classes in mm. Format (10F8.3)

From the gradation curves obtained with the soil samples an average gradation curve was constructed. This curve was subdivided into size classes in the following manner: D100 = (a)mm, D90 = (b)mm, D80 = (c)mm. . . etc. Next, the geometric mean diameter in mm was determined for each 10% size class.

i.e.,

$D_{100} - D_{90} = (a \times b)^{1/2}$ and etc. This procedure was carried out for the entire gradation curve to produce ten particle size classes with a geometric mean diameter assigned to each class.

J. Size Distribution Cards - one card for each response unit. The variable name is PBO(I)-fraction of soil particle for each respective size class on the preceding card I in $\frac{0/0}{100}$. Format (10F8.3). For these tests

$$PBO(I) = 0.1$$

Note - cards I and J must be inserted in the data deck in sequential pairs for the various response units.

K. Sediment Routing Parameters - one card is required for the data set. The parameters entered here are: AIM - rainfall detachment coefficient, BIM - exponent for the rainfall detachment equation, AGB - coefficient for the sediment transport equation, BEX - exponent for the sediment transport equation, and DELTS - which is the parameter for the determined critical shear stress. Format (5F10.3).

For rainfall detachment calculations ROSED utilizes an equation developed by Meyer (11): (Using ROSED parameter names)

$$D_R = AIM\ (I)^{BIM}$$

where: D_R = potential rate of soil detachment by rainfall impact dependent on soil characteristics

AIM = detachment coefficient

I = rainfall intensity

BIM = a constant (2.0)

The rainfall simulator used for this study produces a kinetic energy of about 40% that of a natural rainstorm of the same intensity (Neff,

1979) (20). For this reason the soil parameter AIM was fixed at a value of 0.001 since the contribution of kinetic energy from raindrop impact was very low.

The bedload transport equations in ROSED require the input of the variables AGB, BEX, and DELTS. For all cases these parameters were set at the following values:

AGB = 0.056

BEX = 1.5

DELTS = 0.047

L. Flow Detachment Coefficient - one coefficient for each response unit: ADF(I) - runoff detachment coefficient. This parameter was determined in a method proposed by Simons (22): Format (5F10.3)

$$ADF(I) = \frac{K\ (D_{50})^2}{.63}$$

where: K = soil erosivity index from the Universal Soil Loss Equation by Wischmeier (7)

D_{50} = median soil particle size in mm.

The value of D_{50} was determined from the average gradation curve for the plots. K was determined from the soil erodibility monograph using the average gradation curve and other needed data from the plots.

M. Storm Information Card(s) - one card for each storm: The variables listed on this card are - STORM(I) - Identification of the storm, ITMAX(I) - maximum duration of the storm in numbers of time increments, ITCOM(I) - maximum duration of runoff in numbers of time increments. Format (2X, A8, 2I10)

N. Rainfall Intensity Card(s) - one set of cards for each storm. One intensity value is used for each time increment of storm duration. Variable name - DR(I,J) - rainfall intensity in inches/hour. Format (10F8.3)

APPLICATION OF RAINULATOR DATA TO MODEL BY ROSED DEVELOPERS, Li AND Ward

A portion of the rainulator data was given to Ruh-Ming Li and Tim Ward of Colorado State University for their testing of ROSED. The purpose of doing this was to test the model for sensitivity to different operators and to less experienced operators (authors). The complex model and its many parameters require interpretations in parameter selection and flow routing. If the model is to become a practical planning tool, operator sensitivity needs to be addressed.

Initially, only the results of the study of Li and Ward were to be shown in this report. However, it became apparent that the operation of the model and parameter selection are as important as the results. Therefore, the entire paper by Li and Ward is reproduced here, beginning with Objectives of Report. Only paging, table and figure numbers and ref. nos have been changed to conform to the overall report to avoid confusion.

OBJECTIVES OF REPORT

The objectives of this report are to

(1) present the test data in a form usable by other investigators,

(2) apply the simplified on-site water and sediment yield model to obtain best estimates of model input parameters, and

(3) demonstrate and verify use of the model for estimating water and sediment yield from roadways.

Details of the model are not presented in this report but can be found in the previously cited references. [(21) of main report]

TEST SITES AND DATA

Test Sites

The test sites utilized were road sections in active mining areas in Montana and Idaho. Because of the priority of the data, each site and run is identified by a combination of letters and symbols as shown in Table 6. The letter or letters and the first number identify the road site, and the second number identifies the run designation. Run designation numbers of 2 or 3 indicate "wet" runs where the road was wetted by a previous experiment. Seven data sets for five mines were developed for the collected information. These sets formed the basis for model testing.

Test Data

Data for use in the simplified model can be grouped into geometric, soils, vegetation, rainfall, and sediment and water yields. Because the simplified model tests the road surface as a single plane, each surface was converted to that geometric form. Table 6 lists the geometric characteristics of the test sections.

Soils size data were provided as grain size analyses of "before run", "after run," and "runoff" samples. The before run samples were randomly collected from surface sweepings. Soil moisture and density readings were also collected before and after the runs. The before run size distributions were composited and plotted on log probability paper to obtain the median grain size D_{50} and gradation coefficient G as

$$G = \frac{1}{2}\left(\frac{D_{50}}{D_{15.9}} + \frac{D_{84.1}}{D_{50}}\right) \quad (1)$$

where $D_{15.9}$, D_{50}, and $D_{84.1}$ are the grain sizes at which 15.9, 50, and 84.1 percent, respectively, of the on-site soil samples are finer by weight. Soil porosity n is found from the specific gravity of the soil

Table 6. Geometry of the test sites.

Site	Average Length of Section (ft)	Centerline Slope	Average Width (ft)	Area (ft^2)
C1-1	144.45	.031	33.04	4773
D2-2	76.83	.052	41.28	3171.2
D2-3	76.83	.052	41.28	3171.2
S1-1	122.00	.031	33.30	4062.5
S3-1	114.62	.055	32.34	3707.0
S3-2	114.62	.055	32.34	3707.0
SG2-1	174.11	0.044	33.60	2490.0

particles and the dry specific weight of the on-site soil as $n = 1 - \frac{\gamma_{soil}}{\gamma_w Gs}$ where γ_{soil} is the dry bulk specific weight of the soil, γ_w is the specific weight of water, and Gs is the specific gravity of the soil particles. Soil saturation is found from the gravimetric water content of the soil, w, specific gravity of the soil particles, and the void ratio e as

$$S = \frac{w\ Gs}{e} \tag{3}$$

where

$$e = \frac{n}{1-n} \tag{4}$$

In the simplified erosion model, the final saturation is assumed as 1.0. Although initial and final water contents were provided, the difference between the initial and final was used to determine an adjusted initial value for use in the model. Runoff hydrographs and rainfall rates were used to estimate soil infiltration parameters. In most experiments runoff reached a fairly steady rate before rainfall was terminated. This was not always the case and a distinct peak discharge was evident. In the former instance, the steady rates were averaged to obtain a representative runoff rate, and in the later case the peak rate was selected as representative. The difference between the representative runoff and rainfall rates was defined as a characteristic hydraulic conductivity. This characteristic hydraulic conductivity K_c was used to compute another parameter α that is a combination of soil porosity, initial saturation S, and potential capillary suction head ψ. The value of α was found from

$$\alpha = \left(\frac{i}{K_c} - 1\right) i\ t_p = \psi\ n\ (1 - Si) \tag{5}$$

where i is the rainfall rate and t_p is the time to ponding (the time

when runoff begins). The value of t_p can be estimated from the runoff hydrographs but was provided by observers for each experiment. Results of the on-site soil analyses and the hydrograph computations are presented in Table 7. As this table shows, there is a great variation between sites which helps demonstrate the transferability of the model. Several values presented in Table 7 should have further explanation. Typical experiments consisted of a "dry" (initial) run followed by "wet" subsequent runs. Dry runs have low Si values while wet runs have high Si values. Again, these values are computed for soil moisture measurements and average dry bulk densities. The K_c values show variation between D2-2 and D2-3, perhaps caused by using an averaging rainfall rate. It should be noted that in four data sets, the runoff rate exceeded the average rainfall rate, thus eliminating these sets from analysis. The large difference in K_c values for S3-1 and S3-2 is difficult to determine. At the D2 site it was also observed that initial runs infiltrated differently than subsequent runs. This was believed to be the result of the first run altering the soil surface and moisture conditions. Similar phenomena may be present at the S3 sites. Because of a lack of data, the Si value for SG2-1 was estimated to be the same as S1-1. The values of α presented in Table 7 were estimated from the K_c values. Caution should be exercised if ψ is to be computed from α, Si, and n, since unrealistic answers may result. This is caused by the inherent difficulty in determining representative Si and n values based on limited tests and averaged soil properties. Therefore, the value of ψ, although it has a definite physical meaning, may seem erroneous if it is calculated using estimated and average values of the other variables.

Table 7. Computed and estimated soil characteristics for mine haul road sites.

Site	Median Diameter D_{50} (mm)	Gradiation Coefficient G	Specific Gravity of Sediment Gs	Soil Porosity n	Initial Saturation Si	Difference Between Rainfall Rate and Representative Runoff Rate K_c (in/hr)	Computed α (in)
C1-1	.34	13.74	2.61	.43	.26	.349	.394
D2-2	.35	10.86	2.65	.359	.99	.182	.371
D2-3	.35	10.86	2.65	.359	.99	.375	.159
S1-1	2.0	6.75	2.61	.22	.07	.549	.631
S3-1	1.4	14.42	2.65	.21	.23	.031	5.197
S3-2	1.4	14.42	2.65	.21	.99	.291	.191
SG2-1	3.0	4.79	2.74	.24	.07	.056	1.936

Table 8. Rainfall, runoff and sediment yield for mine haul road rainulator experiments.

Site	Rainfall (in/hr)	Rainfall Duration (min)	Water Yield (ft^3)	Peak Discharge (ft^3/sec)	Runoff Duration (min)	Sediment Yield (lbs)
C1-1	1.596	14	74.15	.14	15	112.6
D2-2	1.806	10	42.76	.12	15	27.94
D2-3	1.806	20	108.82	.11	24	82.65
S1-1	2.208	17	85.11	.16	20	35.59
S3-1	1.854	10	68.73	.16	11	29.59
S3-2	1.818	37	250.47	.13	48	177.30
SG2-1	1.59	14	38.94	.09	19	6.95

Characteristics of the rainfall, runoff, and sediment yield are presented in Table 8. Rainfall rates are averaged from several gages. The rainfall and runoff durations are rounded to the nearest minute, and the water and sediment yields are determined from integrating respective outflow hydro- and sedi-graphs. Because of the large sediment sizes (about the size of gravel), the road was assumed to have a flow resistance factor of abour 400. Grain resistance was selected as 50and kinematic viscosity as 1.05×10^{-5} ft^2/sec. The sites were not vegetated.

APPLICATION AND RESULTS

After data analyses and development, the simplified model was run. In the first run, the K_c value was divided by 2 and used with the computed α value to estimate water yield. Simultaneously, the sediment yield was computed using an overland flow detachment coefficient (D_{of}) of 1.0. If the detachment coefficient is 1.0, it was assumed the flowing water could carry a capacity sediment load. This implies a readily available sediment supply. A detachment coefficient of 1.0 was initially tried to determine if the predicted overland flow could carry the measured sediment yield and to give a starting point at which to begin adjusting d_{of} values to match the measured yield. If the predicted and measured water yields were close and the D_{of} value was 1.0, the predicted sediment yield should be approximately greater than or equal to the measured yield. Under predictions indicate there may be a data error or the model is not appropppiate for application to that set of data. Initial predicted water yields using the hydraulic conductivity equal to one-half K_c and the estimated α were all within 30 percent as shown in Figure 12. The close match of the predicted and measured water yields using rough estimates of the key infiltration parameters validates the

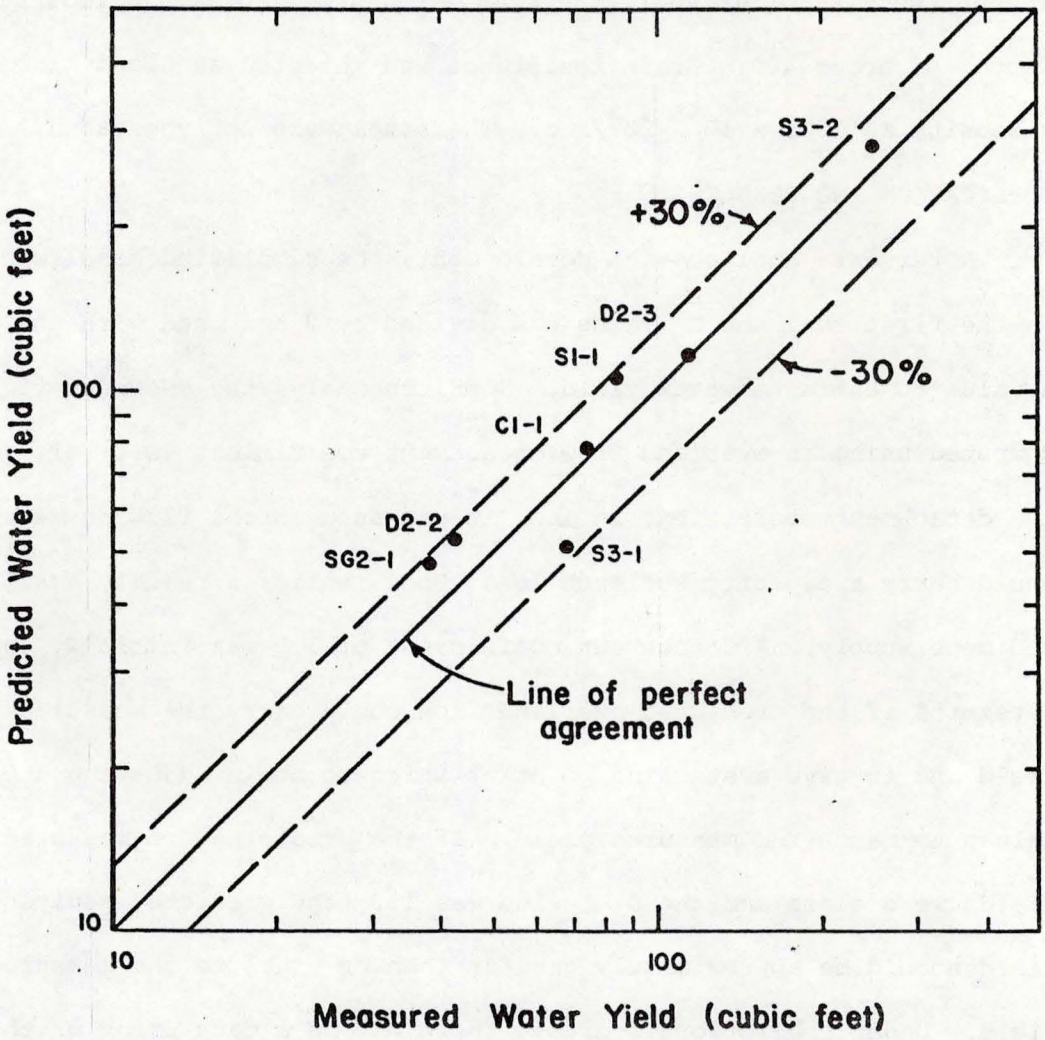


Figure 12. Predicted water yield compared to measured water yield using one half of rate difference as K_w.

application of the Green and Ampt infiltration equation as formulated in the model. No further adjustment was attempted to determine a set of infiltration parameters that produced more accurate results. Instead, the model was run with $D_{of} = 1.0$ to examine the sediment yield predictions. As anticipated, the estimated yields were overpredictions. In order to adjust the D_{of} so the predicted yields approached the measured yields, another set of estimates at a different D_{of} was needed. The relationship between D_{of} and predicted sediment yield at a specific water yield can be represented as a power relationship of the form

$$Y = a\, D^{b} \tag{6}$$

where Y is yield, D is the D_{of}, and a and b are parameters. For the test data, Y and D_{of} are strongly correlated in this form. With two values of Y and D_{of}, the b parameter can be estimated from (taking logs of Equation 6)

$$b = \frac{\ln\left(\frac{Y_1}{Y_2}\right)}{\ln\left(\frac{D_1}{D_2}\right)} \tag{7}$$

where Y_1, Y_2, D_1, and D_2 are the respective values for the first and second predictions. An estimate of the "best" D_{of}, D*, can then be found as

$$D^* = \exp\left[\frac{\ln\left(\frac{Y^*}{Y_1}\right)}{b} + \ln D_1\right] \tag{8}$$

where Y* is the measured yield. If several sets of data for the same site exists, then a power equation such as Equation 6 can be developed from which D* can be estimated directly. A second D_{of} value was computed using the approach suggested by Simons, Li, Ward, and Eggert (1978).

(22) In this approach, the D_{of} is related to the K factor in the Universal Soil Loss Equation as

$$D_{of} = \frac{K\ (Ds)^2}{0.63} \tag{9}$$

where K is determined using a nomograph approach with soil size distribution and other soil properties (Agricultural Research Service, 1975), (24) and Ds is the representative soil size chosen as D_{50}. Values of D_{of} from Equation 9 were used to predict sediment yields based on the previously estimated water yields. Results showed that all predictions were within the same order of magnitude as the measured yields. This result is encouraging since it indicates there is validity to this approach of selecting D_{of}. However, more effort needs to be expended in developing a better understanding of the relationship between the K factor and D_{of}. Comparison of the predicted sediment yields based on the computed D_{of} values indicate an average overprediction of about two times, with a range of predictions from eight times greater to one-seventh of the measured value. The predictions for S3-1 and S3-2 were within four percent of the measured values based on the predicted water yields. The computed D_{of} values for run C1-1 resulted in an underprediction for the sediment yield. An adjusted D_{of} for C1-1 is 0.63. Runs D]] and D2-3 simulations needed a slight upwards adjustment from the original D_{of} to produce better predictions. Runs S3-1 and S3-2 were left at the originally computed D_{of} values. Runs S1-1 and SG2-1 were overpredicted with the computed D_{of} values which needed to be considerably reduced in scale. Although not confirmed, the coarser sediments at these two sites may have a significant effect in lowering the D_{of} value through protection from erosion or providing more flow resistance. Neither of these effects can be confirmed at this time. These adjusted D_{of} values

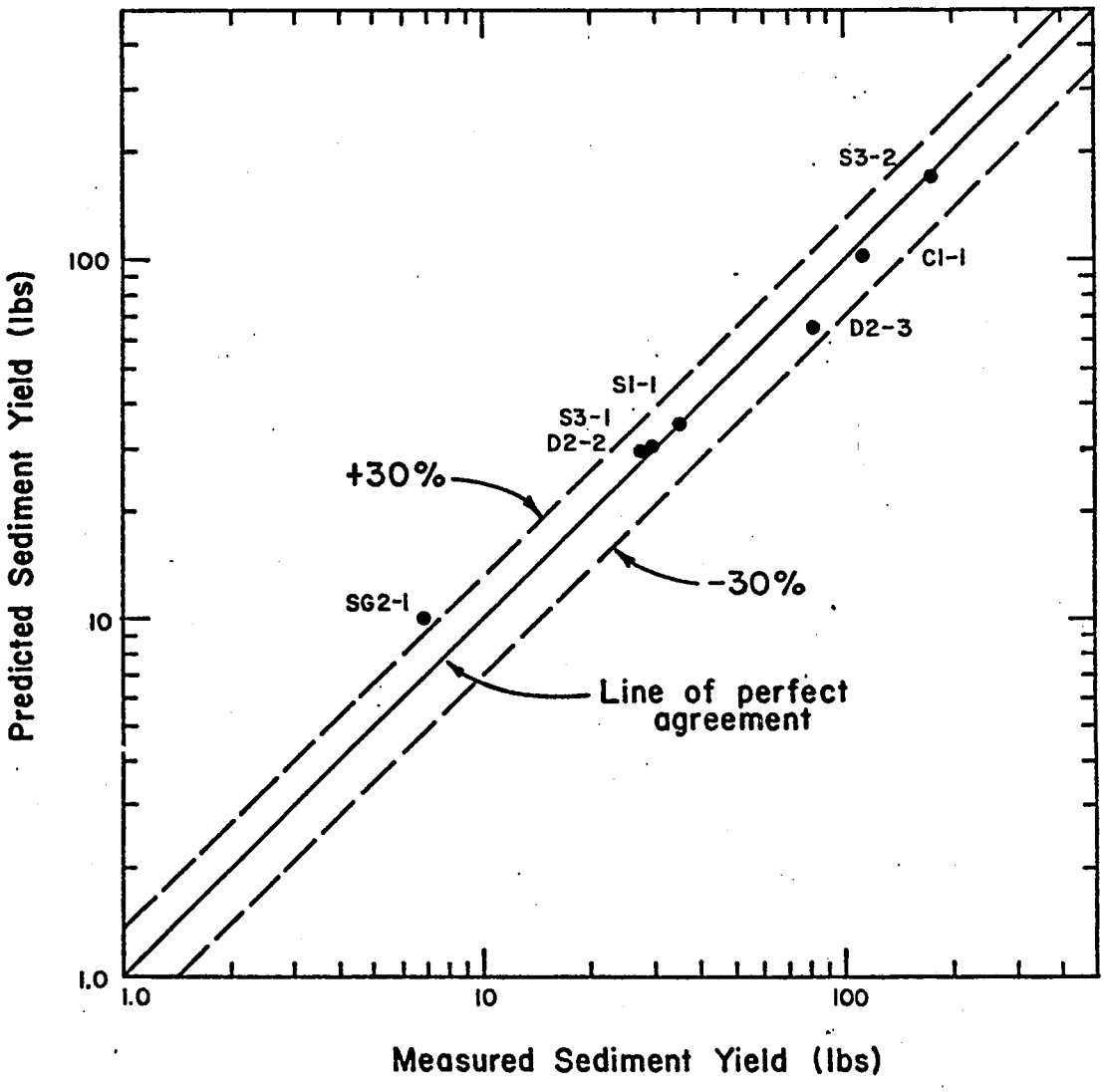


Fig. 13. Predicted compared to measured sediment yield using adjusted runoff detachment coefficients and water yields as previously estimated.

are listed in Table 9, and a comparison of predicted and simulated sediment yields are shown in Figure 13. As Figure 13 shows, the estimated sediment yields are almost all within ±30 percent similar to the water yields. The closeness of these values helps verify that the model can realistically simulate water and sediment yields from roadways.

SUMMARY AND CONCLUSIONS

This report presented an application of the on-site erosion model to data collected in Montana and Idaho. The data were from rainulator experiments on mine haul roads and consisted of rainfall rates, water runoff rates and volume, sediment yield, and various other soil data. Seven experiments proved suitable for analyses. Results indicate the model can realistically predict water and soil yields from mine haul roads using estimated parameters. Further parameter adjustment would produce even better results. These results help validate the use of the erosion model approach in other models designed specifically for estimating water and sediment yield from roadways.

Table 9. Adjusted D_{of} values used to predict sediment yield.

Site	D_{of}
C1-1	.63
D2-2	.23
D2-3	.23
S1-1	.04
S3-1	.37
S3-2	.37
SG2-1	.26

ROSED TEST RESULTS BY MSU

A standardized procedure has been developed for implementing rainfall simulator data in the ROSED model as a result of close communication with the model developers to prevent misinterpretation of model parameters. The approach in this study has been to estimate these model parameters from an operational standpoint with simple measurements of site characteristics as input to the ROSED model.

A total of 24 individual applications of rainfall were made. Of these only 13 sets of data were used to evaluate ROSED. The remaining data sets were eliminated because of errors caused by wind effects, lack of rainfall intensity data, and faulty layout of cutoff ditches.

Graphical displays, together with complementary wind data, showed that unequal distribution of rainfall over the road section caused erratic runoff with hydrographs not suited for rigorous evaluation of ROSED. Wind gusts of as little as 5 mi/hr were sufficient to seriously affect the accuracy of runoff measurements. Four sets of measurements have been omitted because the effect of wind was severe enough to render these data useless. Therefore, evaluations of ROSED are based upon those simulations where rainfall is uniformly distributed over each road section -- a necessary condition for use of this model.

Figure 14 depicts the results of simulated rainfall tests and show the measured rainfall intensity averaged over one minute intervals together with the observed runoff hydrograph. This shows the results of simulated rainfall on highly compacted road sections with low infiltration rates. Note that there is very little difference between total rainfall volume and total runoff volume and between the rainfall rate and the peak runoff rate. This emphasizes that any errors in measurement of the rainfall application

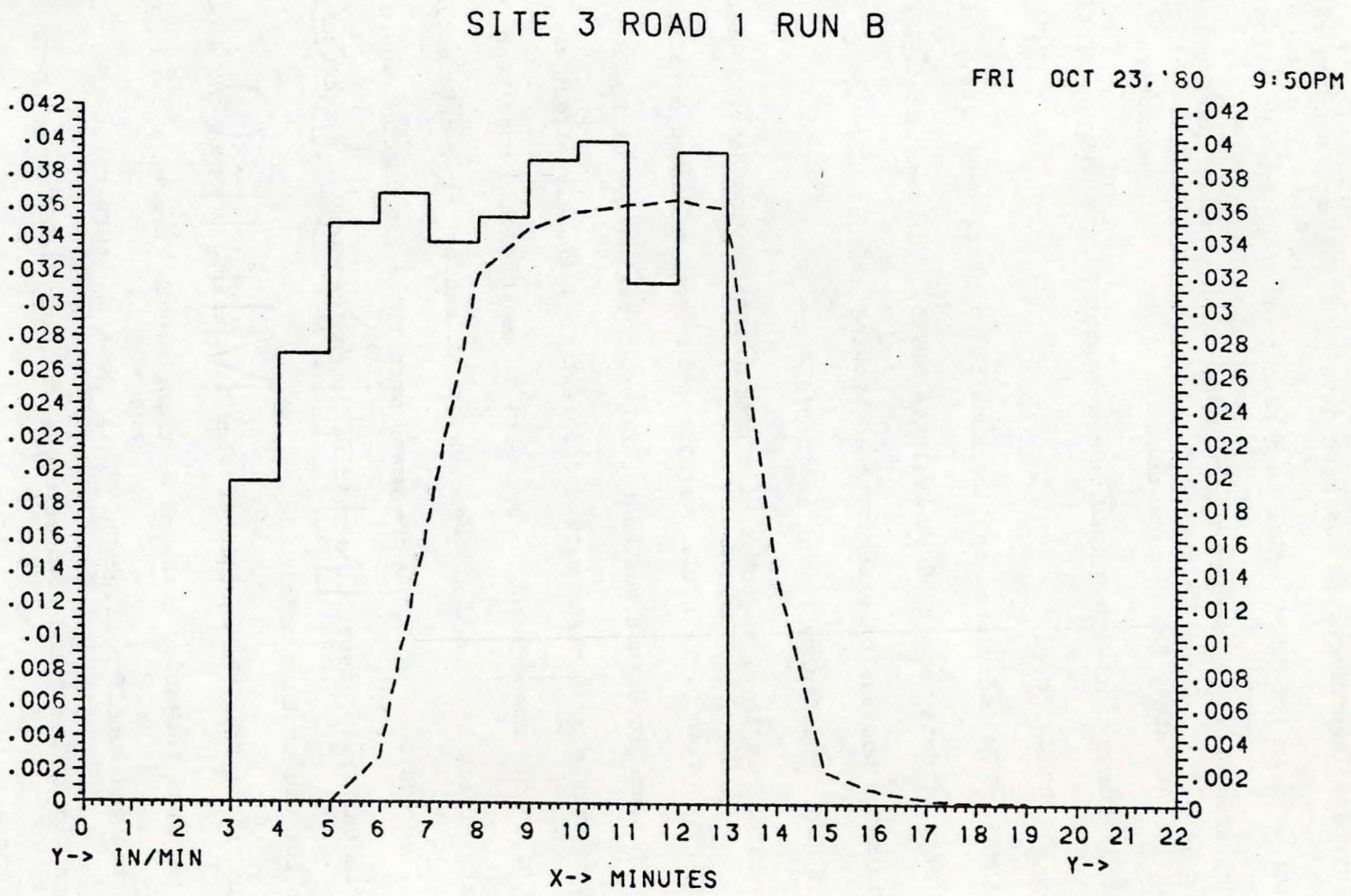


Fig. 14. Comparison of Applied Rainfall Intensity with Measured Runoff.

Table 10. Predicted and measured values of runoff and sediment from selected sets of simulated rainfall data.

Location	Predicted Runoff (m^3)	Observed Runoff (m^3)	Error (%) = $\frac{P-O}{O} \times 100$	Predicted Sediment (kg)	Measured Sediment (kg)	Error (%) = $\frac{P-O}{O} = 100$
Site 1, Road 1, Run A	1.01	1.31	-23	13.74	16.96	-19
Site 3, Road 1, Run A	1.96	1.68	+17	41.14	52.03	-21
Site 3, Road 1, Run B	1.51	1.77	-15	31.89	46.31	-31
Site 3, Road 2, Run C	3.34	3.08	+ 8	47.17	37.51	+26
Site 4, Road 1, Run A	1.99	2.10	- 5	37.92	51.07	-26
Site 4, Road 2, Run A	2.06	2.32	-11	38.28	36.29	+ 5
Site 4, Road 2, Run B	6.57	6.43	+ 2	72.12	92.71	-22
Site 5, Road 1, Run B	10.96	11.39	- 4	122.92	89.04	+38
Site 5, Road 3, Run B	7.81	7.08	+10	88.45	80.42	+10

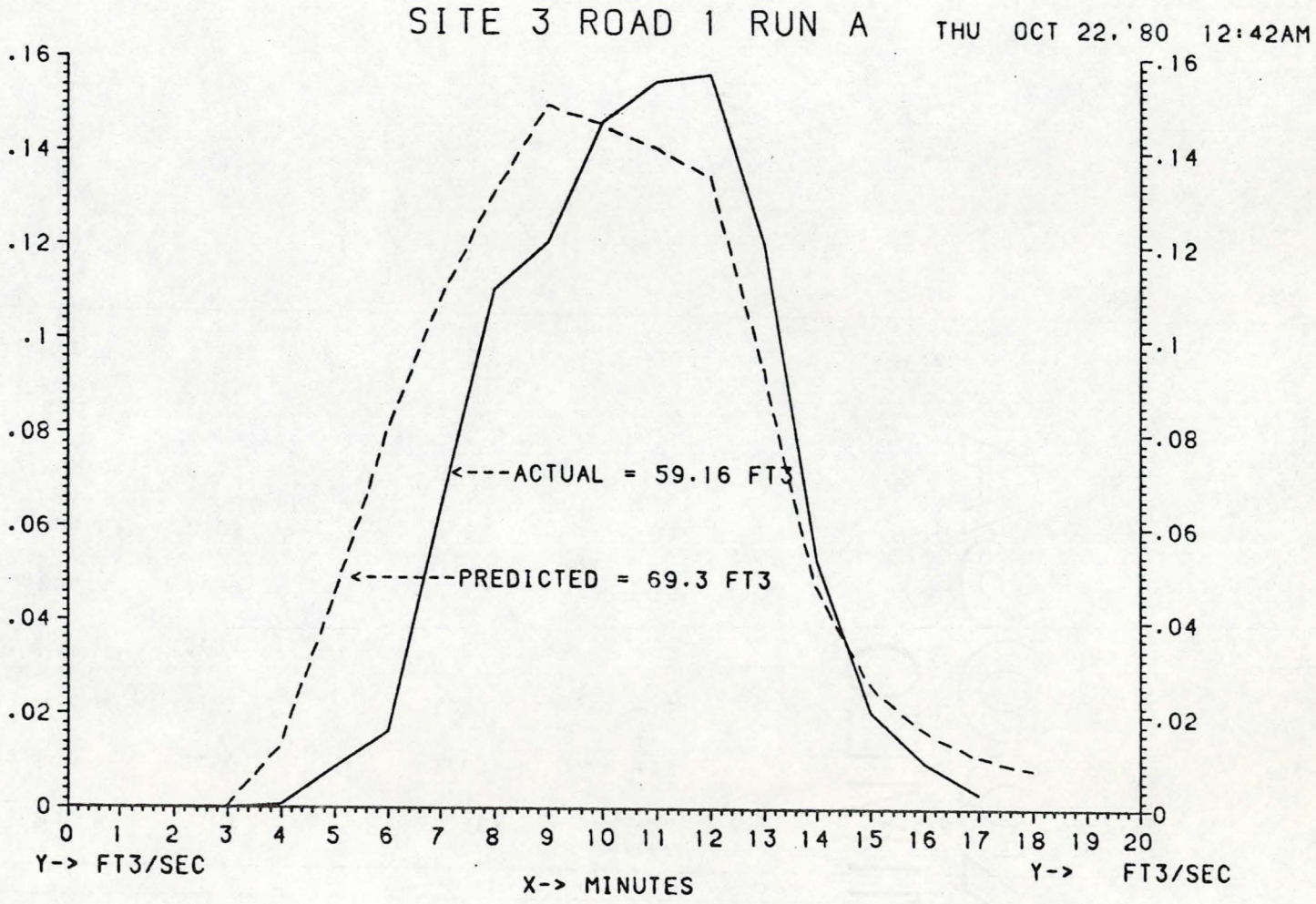


Fig. 15. Comparison of Measured Runoff with Predicted Runoff.

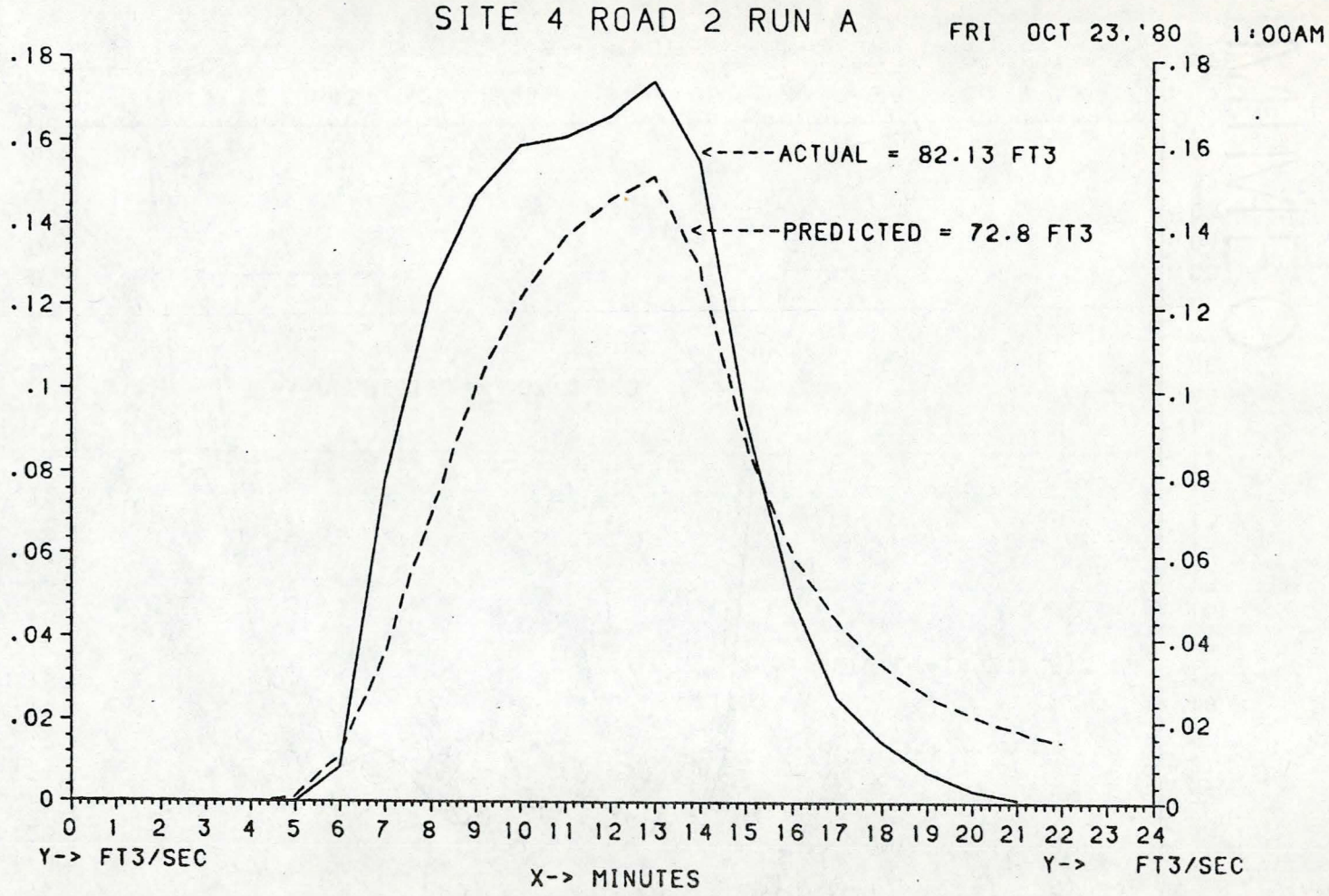


Fig. 16. Comparison of Measured Runoff with Predicted Runoff.

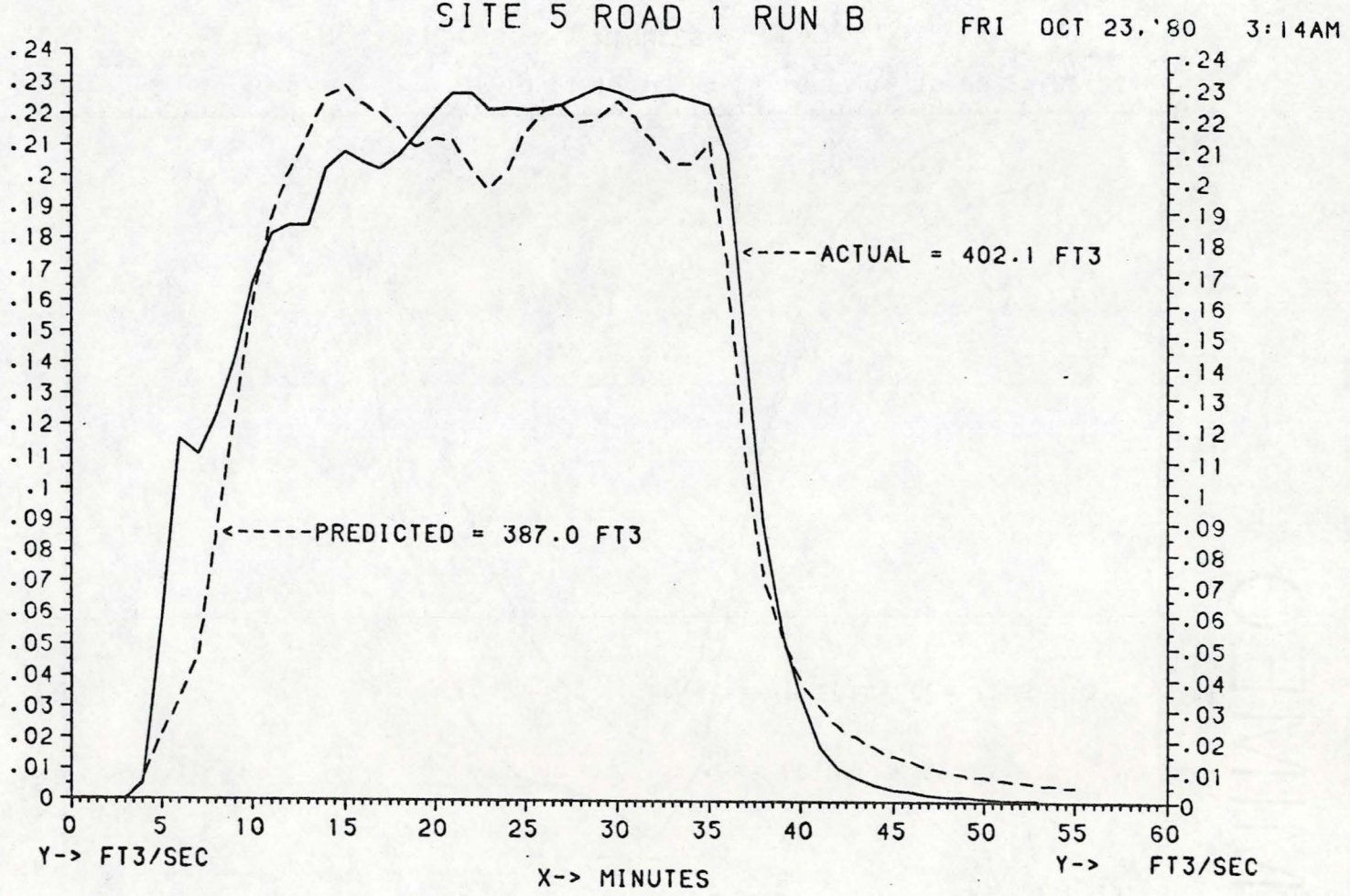


Fig. 17. Comparison of Measured Runoff with Predicted Runoff.

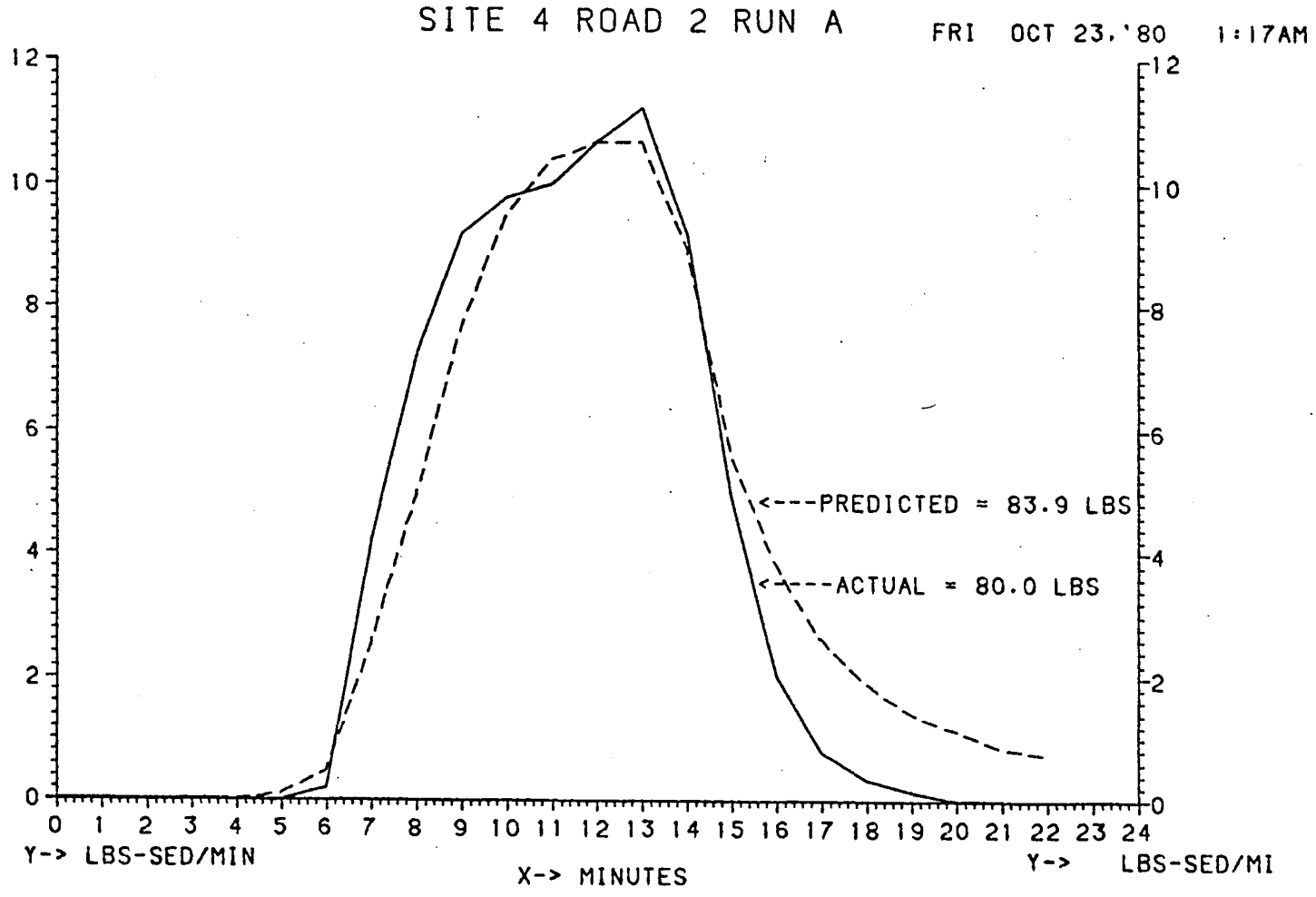


Fig. 18. Comparison of Measured Sediment Yield with Predicted Sediment Yield.

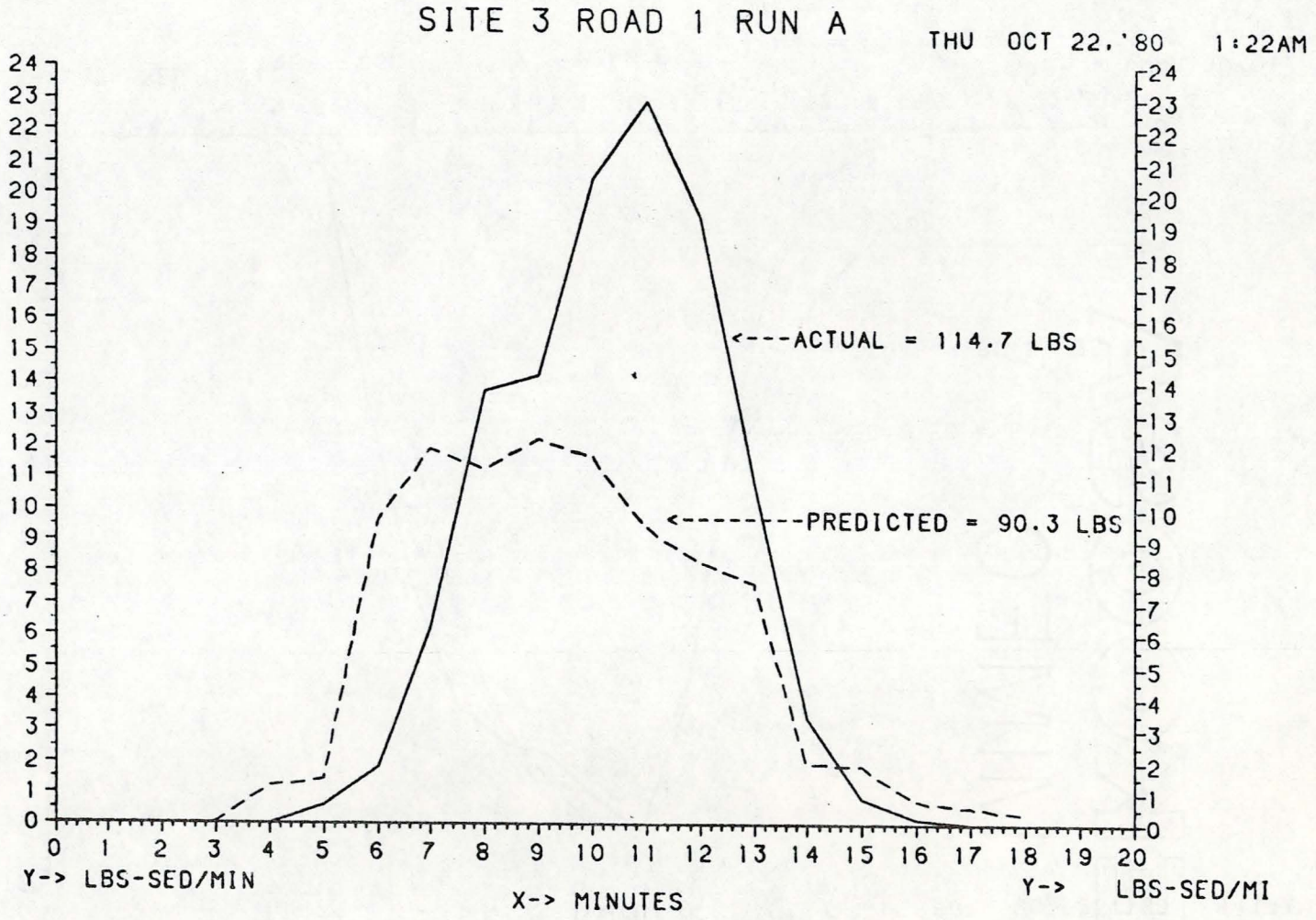


Fig. 19. Comparison of Measured Sediment Yield with Predicted Sediment Yield.

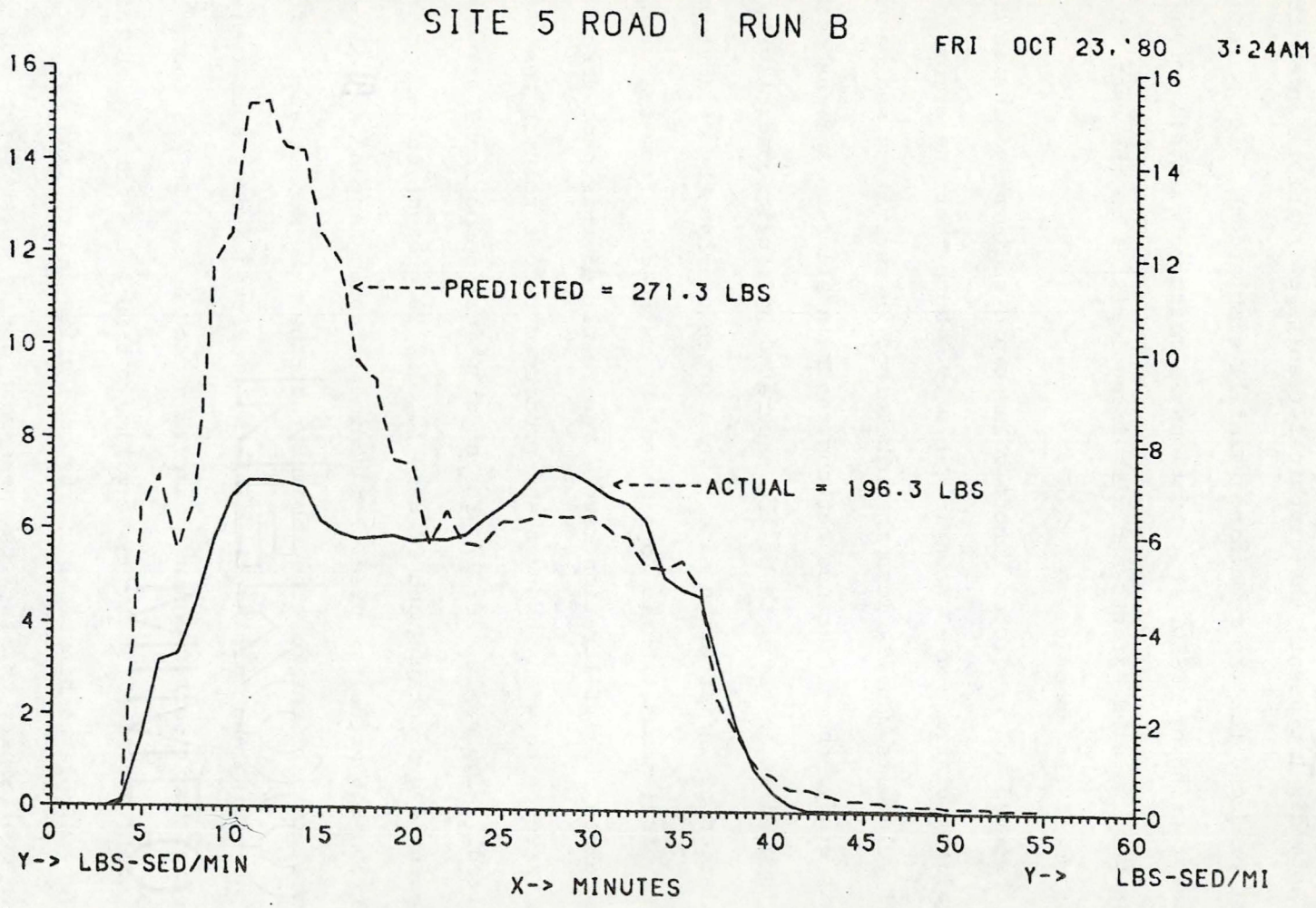


Fig. 20. Comparison of Measured Sediment Yield with Predicted Sediment Yield.

or runoff can cause a significant error in estimation of saturated hydraulic conductivity according to the procedure used in this study.

Appendix I presents the graphical results of rainfall intensity versus runoff produced for the remaining rainfall simulations which were selected for the testing of ROSED. Fluctuations in measured rainfall intensity are due in part to wind effects and also irregularities in the chart drive mechanism of the records.

Observed and predicted runoff volumes and sediment yields from selected rainfall simulations are shown in Table 10. Note that the error in estimating runoff volume is usually less than the error in estimating sediment yield. In this study, the difference between the rainfall rate and the peak runoff rate is used as an estimate of the saturated hydraulic conductivity for calculation of infiltration rate. This procedure has the disadvantage that each rainfall simulation is "optimized" by using data from that simulation to calculate the infiltration rate. The result of this procedure is that the difference between observed and predicted runoff volumes tends to be minimized. Figures 15, 16, 17 present graphical comparisons of some actual vs predicted hydrographs and Figures 18, 19, 20 present corresponding comparisons of actual vs predicted sedimentgraphs. Appendix III presents the graphical comparisons for the remainder of the data sets tested with ROSED.

The rising and falling limbs of the predicted hydrographs typically lag behind their corresponding observed hydrographs. It was found that the model could estimate total runoff volume within ± 10% for 67% of the events.

Very simple combinations of response units and routing sequences were used in preliminary trials with these road data. These first trials yielded mixed results -- some good simulations and some poor ones. The major problem in the poor simulations were the large underestimates of sediment

prediction. In most cases total runoff estimates were satisfactory. A review of time lapse photographs of runoff from these surface mine roads provided valuable insight into how runoff actually moved over each road section. Subsequent modeling runs were more successful because more realistic configurations were used taking wheel ruts in the road surface into account. This procedure made a significant improvement in sediment yield estimates .

The road sections in this study fell into two groups: (1) those in which runoff moved transversely from the road crown to a lateral ditch, down the lateral to the cutoff ditch, and from there to the flume; and (2) those in which runoff moved transversely to ruts in the road surface, then longitudinally down the ruts to the cutoff ditch and from there to the flume. In case 1, there are two short sections of overland flow into two relatively long side ditches; in case 2, several short sections of overland flow empty into several long central ditched (ruts). Figure 21 shows the road cross section configuration for case 1 for both half road widths and full widths as compared to case 2. Dimensions of overland flow length, slope gradient, ditch length and gradient, and ditch side slope were taken from contour maps made for each road section from survey data. Table 11 summarizes the dimensions used.

Figure 22 shows that the form of the predicted sedimentgraphs usually follow those of the measured graphs fairly well, but with quicker rises and faster initial recession as a result of the interconnection with predicted runoff. Comparisons of the predicted measured graphs cannot pinpoint the sources of prediction error; however, the most suspect sources are the soil detachment by rainfall and runoff coefficients, sediment transport, and routing algorithms.

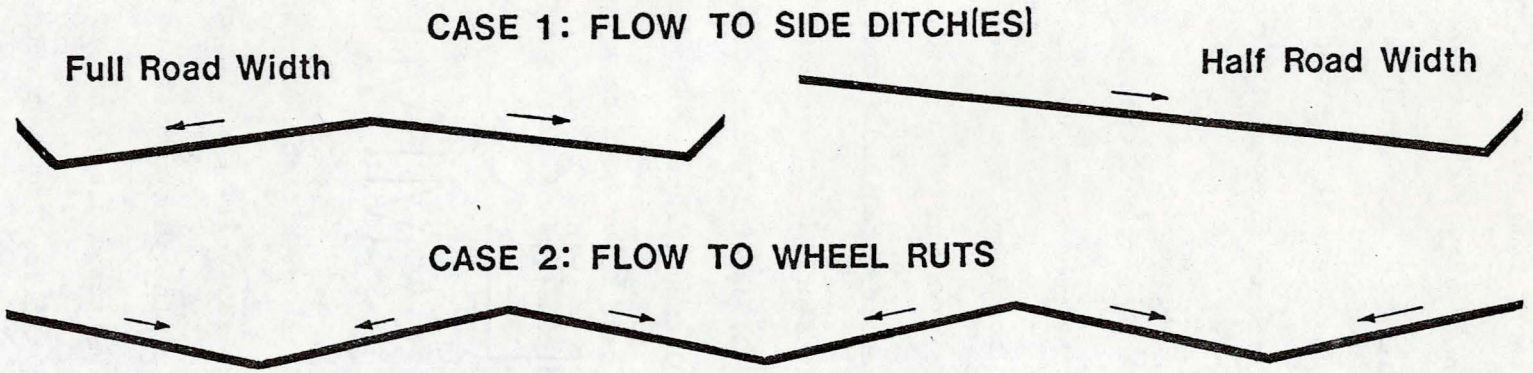


Fig. 21. Three Roadway Model Configurations Used in Analysis of Rainfall-Runoff Data.

The actual sedimentgraphs produced by the rainfall simulation reveal a situation in which sediment concentration is limited by the transport capacity of the runoff. This agrees with the actual field conditions since large amounts of loose soil were recorded on the road surface. This soil had been detached as a result of grading and mechanical abrasion caused by traffic. The model sedimentgraphs indicate a situation where sediment concentration is limited by detachment processes after the initial flush of runoff. Needless to say, more work is needed to determine the appropriate means to optimize these coefficients.

DISCUSSION

The model appears to be quite sensitive to particle size distribution, so careful attention needs to be given to determination of particle size gradation. It was found that discrepancies in soils analysis, caused by different operators, can have a significant effect upon model results.

The analysis of the model results indicate several sources for the errors between predicted and observed hydrographs and sedimentgraphs. First, heavily compacted road surfaces prevented accurate measurement of bulk density with the nuclear equipment used in this study. The equipment utilizes a depth probe, which requires intrusion into the roadbed. Creation of a "probe hole" could not be accomplished without undue disturbance of the immediate area, which caused density determinations to be erratic. Bulk density measurements with surface- type density meters could not give reliable estimates of changes in subgrade density with depth. As a result, only backscatter or surface readings were available. In one particular instance, surface measurements alone cannot adequately describe the changes in observed infiltration rates between the dry and wet simulations.

TABLE 11

Road Geometry - dimensions are as modeled

	Length (ft)	Width (ft)	Slope (%)/100
Site 1 Road 1			
Surface	150.0	20.11	.152
Ditch	20.11	2:1	.153
Site 2 Road 1			
Surface	78.8	35.05	.028
Ditch	35.05	1:1	.032
Site 2 Road 2			
Surface	76.61	32.5	.044
Ditch	32.5	1:1	.045
Site 3 Road 1			
Surface 1	7.22	69.7	.067
Surface 2	7.22	69.7	.067
Surface 3	7.22	69.7	.067
Surface 4	7.22	69.7	.067
Surface 5	7.22	69.7	.067
Surface 6	7.22	69.7	.067
Ditch 1	69.70	4:1(sideslope)	.064
Ditch 2	69.70	4:1	.064
Ditch 3	69.70	4:1	.064
Ditch 4	10.00	4:1	.080
Site 3 Road 2			
Surface 1	36.81	20.0	.061
Surface 2	40.16	20.0	.06
Surface 3	45.00	36.26	.052
Ditch 1	20.00	2:1	.052
Ditch 2	20.00	2:1	.052
Ditch 3	36.26	2:1	.052
Site 4 Road 1			
Surface	32.92	137.6	.0524
Ditch	137.60	2:1	.031
Site 4 Road 2			
Surface	32.44	131.34	.028
Ditch	131.24	2:1	.016

Table 11 (Continued)

	Length (ft)	Width (ft)	Slope (%)/100
Site 5 Road 1			
Surface 1	46.88	49.39	.0512
Surface 2	52.51	52.51	.0321
Ditch 1	49.39	2:1	.031
Ditch 2	52.51	2:1	.031
Ditch 3	10.0	2:1	.04
Site 5 Road 2			
Surface 1	60.02	7.24	.0275
Surface 2	84.51	35.82	.0276
Surface 3	80.00	35.82	.03
Ditch 1	7.24	2:1	.027
Ditch 2	35.82	2:1	.027
Ditch 3	10.0	2:1	.03
Site 5 Road 3			
Surface 1	19.55	66.56	.066
Surface 2	40.35	59.63	.063
Ditch 1	66.56	2:1	.055
Ditch 2	59.63	2:1	.055
Ditch 3	10.00	2:1	.059

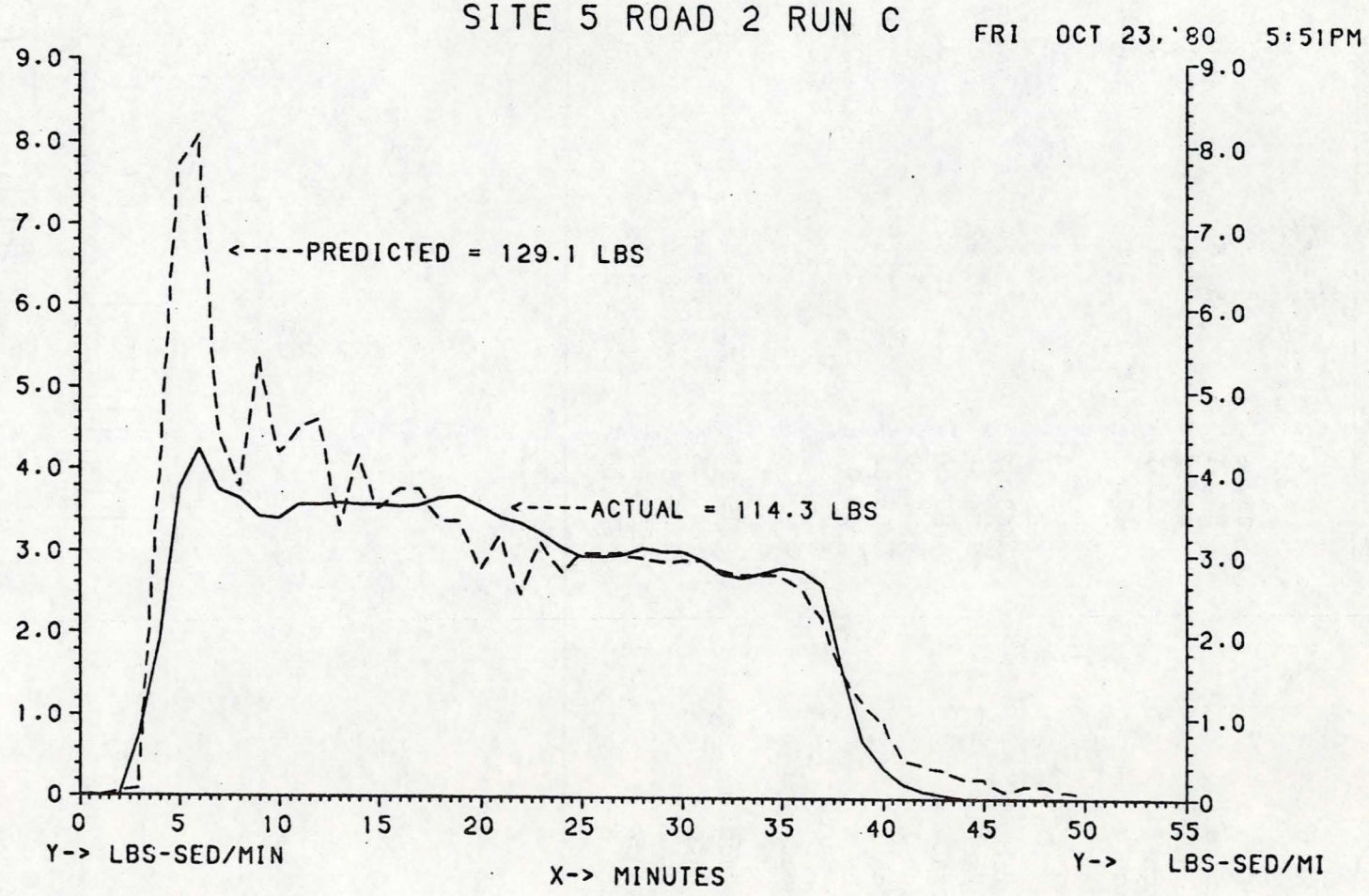


Fig. 22. Comparison of Measured Sediment Yield with Predicted Sediment Yield.

The high density of the surface material also confounds accurate determination of soil moisture contents before and after applied rainfall because of the limited pore space in the soil. Inaccurate measurements of both bulk density and soil moisture content can seriously affect the accuracy of infiltration rate calculations using the procedure in the model.

Rainfall detachment was assumed to be negligible in this study and the model parameter was set at a low value, but more work needs to be done on measurement of rainfall detachment. This subject is especially important considering the increasing use of rainfall simulators with applied kinetic energy significantly less than for natural rainfall events.

Simple response units were first used in ROSED to model road configuration, whereas real roads include a combination of planes and flow channels as a result of heavy truck traffic that creates shallow ruts. These wheel ruts are almost unnoticeable on the very dense, well maintained mine haul roads; but they cause concentrations of runoff that can create a difficult problem for the model builder. Further tests with ROSED proved that it was necessary to model these characteristics in detail to attain more accurate sediment yield prediction.

CONCLUSIONS AND RECOMMENDATIONS

Experience of this study with the ROSED model is generally positive. ROSED represents a major step in the development of an operational planning tool to estimate runoff and sediment yield from low standard roads. ROSED has the capacity to model different road prism configurations, but more flexibiility is needed to model various ditch shapes and ditch side slopes.

Simulated rainfall allows testing of the ROSED model on road sections with various characteristics of slope shape and surfacing. These tests allow the user to determine the sensitivity of model parameters over a range of site characteristics. Further development is needed to relate model parameters to site characteristics so that ROSED may be used by land managers and resource specialists not familiar with the mechanics of this model.

Field Procedures

The use of simulated rainfall offers opportunities for systematic evaluation and testing of runoff and erosion models for use on roads. Field experience with simulated rainfall indicates several areas where improved field technique would result in better data. These improvements would give better resolution of data, expedite analysis, and lower the possibility of errors in analysis of samples.

The non-recording rain gauge grid should be extended 1 to 2 meters beyond the plot boundaries in order to improve estimation of the aereal distribution of rainfall. The extended grid would improve estimated distribution by isohyetal and Thiessen polygon methods. In addition, computer drawn isohyetal maps could be developed from digitized catch results. Two or more tipping bucket rain gauges should be randomly located within the plot to provide accurate rainfall intensity data.

A multichannel recording system is needed so that rainfall records, dye travel times, time to ponding, etc., all appear on a single chart with a common time base. This would help speed data analysis and reduce errors caused by using data from several different types of charts each with its own time scale. Runoff hydrograph charts would continue to be separate, but the stage recorder would use a 1-minute tick mark from the

multichannel master recorder so that the hydrograph can be related exactly to the common time base. An example of the possible inputs for the event recorder might be:

Channel number

1 - time (one mark per minute)

2 - storm events - such as start of rain, time to ponding, beginning of runoff, end of rain, and end of runoff

3 - sediment sample times

4 - wind speed

5 - dye travel times (distance is constant)

6 - to --- - tipping bucket raingages

It is envisaged that timing of dye travel and sediment sampling would be done by remote sensor, triggered by an observer, to an assigned channel. The recorder would require a reliable and accurate master timer and chart drive mechanism.

Techniques are needed for better integrated measurement of soil moisture in the upper 5 cm of the road surface --- particularly at or near saturation. This would not be a problem for lesser compacted soils. Gravimetric samples taken immediately after rainfall ceased did not provide information on soil moisture at depth. These samples were not related to a known volume so that accurate estimates of percent saturation could be made. Surface soil moisture measurements with neutron scattering equipment were tried and abandoned because they were too time consuming. Also, they caused excessive disturbance of the plot surface and compromised the accuracy of succeeding simulator runs.

Another improvement would be the use of portable digitizing equipment with a telephonic link to a computer. This would allow checking each

day's charts for major shortcomings in data prior to moving the rainfall simulator to new location. Software packages, such as those developed by Pexton and operating in a host computer, could be called from remote locations and used for preliminary analysis. The cost would be nominal when compared to the potential losses derived from unuseable data.

Future Model Development

Experience with the ROSED model that was used indicates it cannot be used as an operational planning tool as it now stands primarily due to its complexity and the non availability of some input parameters to the planner or manager. This study has shown several specific developmental needs that would greatly improve the utility of this model. The engineer or resource specialist concerned with estimating runoff and sediment yield from an existing or proposed road has limited specific information to work with: soil particle size gradation, bulk density, road prism geometry, and storm characteristics.

Techniques are needed to relate this elementary information to parameters used in the model. Specific model parameters requiring attention are: hydraulic roughness of the road surface, infiltration and hydraulic conductivity, and soil detachment by rainfall and runoff. Simons, Ti, and Shiao (1976) (23) have recommended development of regional handbooks for field use of ROSED "to evaluate alternative routes and alternative designs of road cross sections, road gradients, and surfaces, cut slopes, embankments, and spacings of cross drains." Effects of design alternatives on water and sediment production would be derived manually by the use of nomographs. This type of procedure is the ideal approach for the planner or management specialist.

The addition of a snowmelt subroutine to ROSED would greatly increase the utility of this model for use in the northern tier of states, especially

in mountainous regions. At this time, the mechanics of sediment movement at the soil/snowpack interface is not well understood. Modeling a snowmelt event may only require complete suppression of detachment raindrops and overland flow in order to emphasize channel flow detachment and transport.

Interpretation of the model indicates that while ROSED can be configured to represent wheel ruts, only one side slope can be used for all ditches and wheel ruts. The model also assumes a V-shaped configuration for all ditches and wheel ruts even though trapezoidal or hyperbolic shapes may be found in the field. These constraints limit the flexibility needed to simulate the actual shapes of the road surface, ditches, and wheel ruts.

The importance of the ability to simulate wheel ruts cannot be overemphasized. Our observations of surface erosion from forest roads show that wheel ruts can be an extremely important feature in routing water and sediment from the road surface. Another feature which could improve model predictions is the capacity to handle backwater situations where velocity and transport rates are lowered due to ponding situations or changes in gradient.

In summary, it appears that the ROSED model can predict sediment production from roads. Its successful use by land planners and managers will depend on adapting the model to input parameters that are readily obtained and understood. Considering the complexity of the physical system of erosion, ROSED represents a milestone in sediment modeling.

PART 2

AN OVERVIEW-MODELING THE CHEMICAL AND BIOLOGICAL DEGRADATION OF THE WATER RESOURCE DUE TO ROAD CONSTRUCTION AND USE

INTRODUCTION

The construction and use of a highway introduces two general perturbances into the environment as related to runoff water. The first, involves a change in the quantity of runoff due to the creation of large impervious expanses, changes usually in local drainage patterns, the rate of runoff, and the concentration of runoff into point or multiple point sources. The second, involves a change in runoff quality because of a change in the character of the 'right-of-way' surface and because of depositions from vehicular traffic. This peturbation may be classified into three categories: (1) Physical, (2) Chemical and, (3) Biological. Each of which represents a potential impact on the environment.

In the study of water quality, the watershed, which the highway will traverse, is taken as the unit of study. Within the watershed, many working systems exist, such as soil - plant - animal and water - atmosphere. Once the 'system' is defined, the impact caused by the changed environment can be ascertained. Water quality criteria help determine whether the impact is negative or positive. An ability to predict water quality changes by some modeling technique would thus be of considerable value in the planning stage of any road scheme.

A model relating to physical pollution, that is, sedimentation as a result of erosion with particular reference to mine haulage roads has been developed by Colorado State University, in cooperation with the U.S.D.A.. However, as yet, there is no model specifically describing chemical and biological changes in a watershed as a result of construction and operation of a roadway. In this report, a literature survey is carried out to find both data and material which would be applicable to the development of such a model.

BACKGROUND

Man's impact on the quality of water has not received a great deal of attention in studies until relatively recently. There are many reasons for this, but the basic one is, that the environmental costs associated with stream pollution were considered insignificant. As a consequence of the long history of concern over water quantity problems, far more data is available on streamflow quantity than quality. It was not until the late 1960's and 1970's that research began in earnest to determine the nature of the constituents of specifically pavement runoff waters and their effects on the watershed ecosystem.

As has already been mentioned, the environmental impact of a highway activity on water quality may be classified into three categories (1) Physical, (2) Chemical, and (3) Biological. This impact can also be separated into three distinct stages - those effects related primarily to the construction of the facility, those effects attributable to the operation and use of the facility, and the effects associated with the maintenance of the systems.

During the construction of a highway, physical pollution will be the principal problem as regards water quality. Erosion of highway slopes exposed by the extensive cut and fill operations usually required, will be a considerable source of sediment subsequently to be deposited in streams and lakes. The adverse effects of erosion and sedimentation will include the addition of nutrient materials such as nitrates, phosphates and carbon compounds leached from the sediment. These nutrients will help to accelerate eutrophication (the natural ageing process) of the water system. Sediment deposits on the streambed are detrimental to the propagation of fish which rely on clean gravel beds for spawning. Deposits of eroded material in drainage systems will also decrease the

flow capacity of the facility.

During the operation of the highway all three categories of pollution will be in effect. Aside from maintenance practices, chemical pollution as a result of deposition from vehicular traffic will predominate: residues from burned and unburned fuel and wearing tires, flushing of vehicle underbody accretions and components, lubricants, eroded asphalt particles, accidental chemical spills. Table 1 gives a more complete listing. Atmospheric fall-out is also a source to be considered in the overall assessment. A significant portion of the nefarious substances emitted along a highway are from the vehicle exhausts. Present data indicates that a major portion of this is swept off the road surface to later deposit along the roadside or to be carried away by air currents. Those fractions deposited on a right-of-way soil surface are probably largely retained in the soil; although, there is no specific evidence to corroborate this hypothesis other than the large amounts of lead (from antiknock compounds) that have been found in the soil adjacent to highways. The lead alkyls and organic scavengers are mostly retained in the exhaust system at low speeds and then discharged in increasing quantities as the vehicle speed increases.

The possibility of biological pollution is somewhat limited. The sources of such pollution are; organics from deceased or destroyed vegetation, contaminants from sewage facilities at rest stops and animal carcasses.

Road maintenance practices are a considerable and probably the chief sources of chemical pollution on highway surfaces. These include additions of pesticides for the control of weeds and insect pests, soil sterilants and fertilizers and the addition of oil as a dust control measure in the case of unpaved roads. Snow and ice control on highways

Table 1. Sources and Constituents That Affect Roadway Runoff Water Quality

	Source	Constituent
1	Vehicles	Lubricants, hydraulic fluids, coolants, rubber from tires, dirt carried on under carriages and fenders, wearing vehicle components, fuel residue, particulate exhaust emissions, brake and clutch lining materials.
2	Street surface material	Asphalt and its decomposition products, Portland cement, aggregates, road marking paint, expansion joint compounds, crack fillers.
3	Atmospheric fallout	Deposited airborn materials.
4	Runoff from adjacent areas	Silt, leaves, grass clippings, soil stabilizers, growth control compounds.
5	Litter	Tobacco and numerous other items.
6	Spills	Oil spills, chemical spills, etc.
7	Ice control compounds	Salt and additives.

involves ploughing, use of abrasives and salts. These salts, sodium chloride or calcium chloride are usually mixed and distributed with the abrasive (sand). Special additions are found in some deicing salts such as complex cyanides for anticaking effects and chromates or phosphate compounds for corrosive inhibition. Road salts are usually applied at rates of 400 - 1200 pounds of salt per mile per application, which may result in over 100 tons per mile being applied per season. These salts have had adverse effects on roadside vegetation and on surface and groundwater. Small amounts of the toxic cyanides harm water biota and are cause for rejection of public water supply use; and the phosphates may stimulate undesirable aquatic growths. The effect of these deicing salts in any given instance is dependent upon the rate of application, the amount of diluting water receiving runoff, the rate of runoff and the nature of the roadside vegetation.

The quantity and quality of most substances washed from a roadway is primarily a function of the number of vehicles passing, their speed, the number of dry days preceding a given rainstorm and the quantity of rainfall. The first flush from a rainstorm contains the largest concentration of pollutants which then diminish logarithmically as the rainstorm continues. (1)

A LITERATURE SEARCH FOR DATA RELATING TO CHEMICAL QUALITY OF HIGHWAY RUNOFF

The literature contains information on urban runoff quality but very little on runoff specifically from highways. Street and paved area runoff is not directly comparable to freeway or highway, because runoff onto the city streets from adjacent land areas differs from most right-of-way runoff and there are different air turbulence patterns. Pollutants from a large

urbanized area are generated from paved and unpaved areas where the percentage of road surface and its pollution contribution is relatively small compared to that from roofs, lawns, sidewalks, parking areas, etc.

It is virtually impossible to precisely estimate the amount of pollutants that reach the road surface from source emission calculations, since the pathways that the pollutants follow are highly variable and unmeasured. Therefore, it is more accurate to measure the amount of pollutants that are washed off the road surface and to measure the vehicle released airborne matter that settles out.

Four studies were found where the runoff quality was measured directly from the highway surfaces. Soderlund (2) measured the concentrations in meltwater from a 55,000 vehicle per day highway in Stockholm. Sylvester (1), carried out an investigation for the Washington State Highway Department into the nature of the runoff and particulate emissions from the State Highway 520 bridge over Portage Bay in Seattle. In a preliminary study for the municipality of Seattle, Dalseg and Farris (3) measured runoff pollutant concentrations on the northbound section of Interstate Highway 5. The most recent study was that carried out by Caltrans, (California Dept. of Transportation) in which a comprehensive investigation was made to describe and quantify pollutants in highway runoff during storm periods. The study was conducted in the urbanized area of Los Angeles (I - 405), the San Francisco Bay area at Walnut Creek (I-680) and a rural area east of Sacramento near Placerville (Route 50). Samples were procured at various intervals during a storm in order to describe the variations in concentrations with time and flow. Some 34 different parameters were either measured in the field or determined in the laboratory. These are enumerated in Table 2. (4).

Caltrans found that there was an apparent peak concentration of metals and nutrients (nitrate, ammonia, kjeldahl nitrogen, total phosphate and

TABLE 2

Water Quality Parameters Measured by California Department of Transportation (4)

Temperature*	Cadmium
pH*	Calcium
Specific Conductance*	Chromium
Total Solids	Copper
Volatile Portion of Total Solids	Iron
Total Suspended Solids	Lead
Volatile Portion of Total Suspended Solids	Magnesium
Chemical Oxygen Demand	Manganese
Nitrogen, Kjeldahl	Molybdenum
Nitrogen, Ammonia	Nickel
Nitrogen, Nitrate	Potassium
Phosphate, Total	Sodium
Orthophosphate	Zinc
Oil and Grease	Carbonate
Chloride	Boron
Sulfate	Silica
Bicarbonate	

*Field Measurement

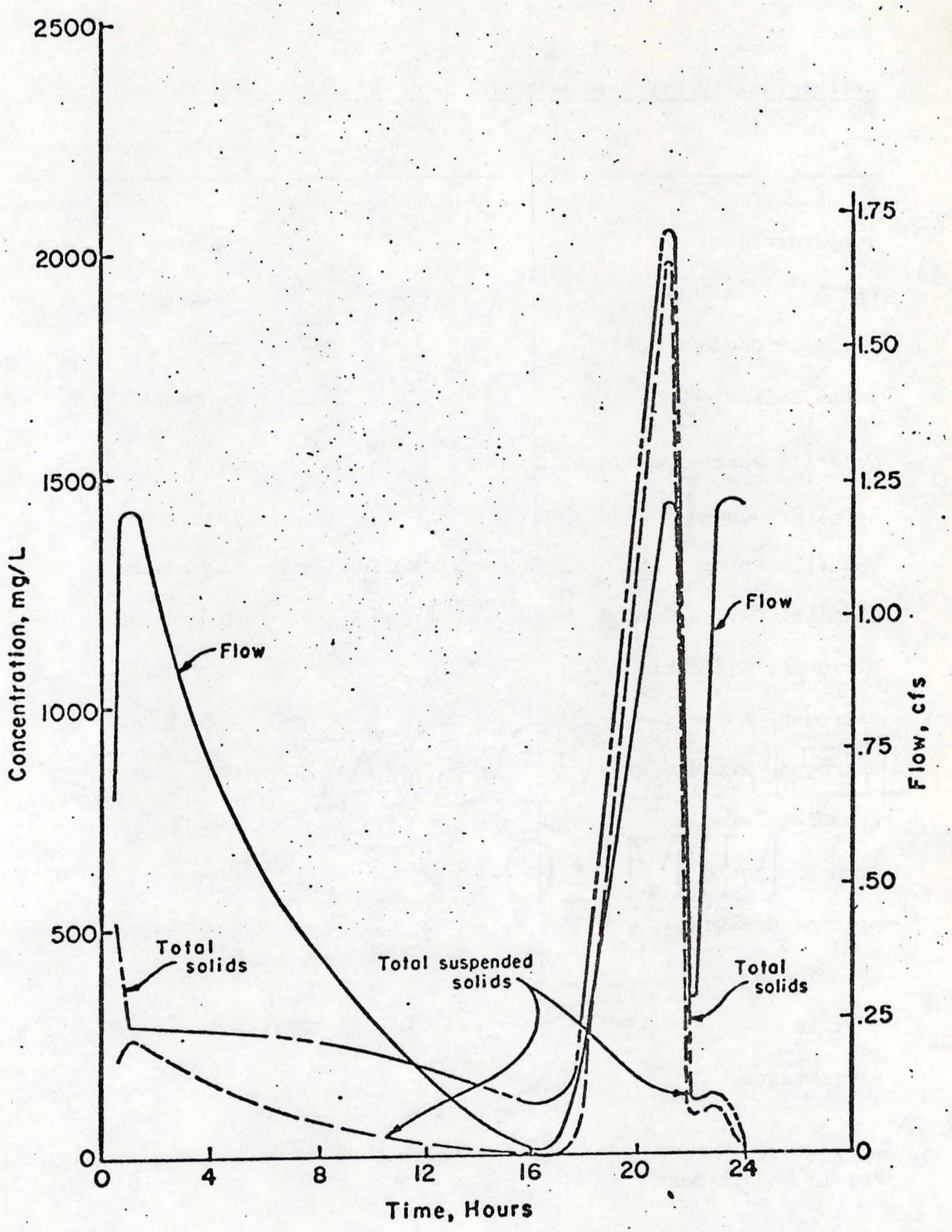


Fig. 1. Typical Pavement Runoff Hydrograph by Caltrans (4).

orthophosphates) and high conductivity at the beginning of storm runoff. The concentration of these materials and conductivity decreases symmetrically with continuing storm water runoff. Total solids and total suspended solids, COD, oil and grease concentrations seem to follow the variation in the runoff hydrograph. Figure 1 from the Caltrans study shows a typical hydrograph. The parameters related to highways, that appear to be most important in terms of water quality standards according to Caltrans, are shown in Table 3. This study is particularly valuable as the data was derived with future application in developing a predictive model for highway runoff very much in mind. Indeed, Caltrans will shortly be undertaking a new research project (A-8-50) entitled, 'Modeling Transportation Pavement Runoff'.

In urban studies, Shaheen (5) determined traffic dependent rates of street surface contaminants in the Washington, D. C. area. As illustrated by Table 4, a wide range of pollutants were identified. Shaheen concluded that pollutants such as grease, petroleum, n-paraffins, lead, zinc, copper, nickel, chromium and asbestos originate directly from motor vehicles. Other contaminants, volatile solids, BOD, COD, phosphate, nitrate, nitrite, chloride and the magnetic fraction appeared to be more a function of local geology rather than directly traffic related. He also concluded that such contaminants as polychlorinated biphenyls and small amounts of cadmium were unrelated to vehicular traffic.

Avco Economic Systems Corporation conducted an investigation into the pollution concentrations and levels from storm water runoff in an urban area at Tulsa, Oklahoma (6). Regression analyses based on the data obtained were used to determine predictor models for estimating urban pollutant concentrations.

Similar short studies have also been carried out in the U.S.S.R. at Minksk by Pravoshinsky (7).

TABLE 3

Most Important Water Quality Parameters Measured by California Department of Transportation Pavement Runoff Studies (4)

Boron	Iron
Chemical Oxygen Demand	Lead
Conductivity	Zinc
Nitrate	Oil and Grease
Kjeldahl Nitrogen	pH
Ammonia	Sulfate
Total Phosphate	Total Solids
Orthophosphate	Total Suspended Solids

TABLE 4

Traffic-Related Roadway Deposits

(Washington, D. C. Metropolitan Area) (5)

Parameter
Volatile Solids
BOD
COD
Grease
Total Phosphate-P
Nitrate-N
Nitrite-N
Kjeldahl-N
Chloride
Petroleum
n-Paraffins
Asbestos
Rubber
Lead
Chromium
Copper
Nickel
Zinc
Magnetic Fraction

MODEL DEVELOPMENT

A formal model is a symbolic, usually mathematical representation of an idealized situation which has the important structural properties of the real system. Formal models are of two general types; deductive-nomological (deterministic) models which allow only predictions with certainty and inductive-probabilitic (stochastic) models which allow only prediction in the form of probability statements.

As of now, no researcher has developed a comprehensive methodology for the predictive modeling of highway runoff chemistry. Empirical relationships have been derived, e.g. the AVCO study mentioned in the last section. However, for the most part, this type of modeling is too site specific and its application is limited to situations with equivalent conditions.

For universal applicability, it is necessary to develop a mathematical model based on fundamental laws describing and interactions which take place during the runoff process.

The principal considerations in the development of pollutant transport model should be the data that is required, the component processes that must be included and the level of results that are necessary. All other considerations being equal, data availability is a key factor in the modeling approach to be used. Where data is available, empiriscisms and analytical techniques may be used which can simplify the model. Where data is unavailable for the specific variables of concern, the approach must rely upon assembling and linking process representations that have been derived from independent studies. Reasoning, together with physical laws, may then be used to develop a mechanistic model.

Since a universal model would be the ideal, the work reviewed subsequently is selected on the basis of its relevance to the development of a deterministic type methodology.

THE COMPONENT PROCESSES

The first stage in predicting the movement of pollutants from the highway through the watershed, should be to determine the amount of runoff that the right-of-way will generate from a given precipitation event. Numerous hydrologic models are available that attempt to do this. Models have been developed to cover the complete range of land usages, from urban to mountain wilderness. Since this report is primarily concerned with chemical pollution prediction from mine haulage roads, only models developed for the more rural type environments will be considered.

Most models are based, or make reference to the Stanford watershed model developed by Crawford and Linsley (8), the Kentucky watershed model (9) or the Texas watershed model, Claborn and Moore (10). These models simulate the 'gross' hydrologic processes of a watershed, i.e. precipitation, interception, overland flow, interflow, deep percolation, and base flow. A schematic representation of this is shown in Fig. 2.

A model developed by Knapp (11) simulates the hydrology of a stream basin including both the surface water and groundwater and has been applied to the Little Arkansas river in southcentral Kansas. Huggins (12), has a similar model which has been tested on two agricultural watersheds in Illinois. Leaf and Brink (13) have developed a watershed model for application to high mountainous Colorado subalpine watersheds. This model also includes the effects of snow and snowmelt. The Wisconsin hydrologic transport model, Patterson (14), is structured similarly to receive atmospheric input to the watershed canopy and simulate its movement until it is discharged as streamflow.

At this point, it should be made clear, that chemical pollution from a highway may either go into solution in the runoff or may be adsorbed by

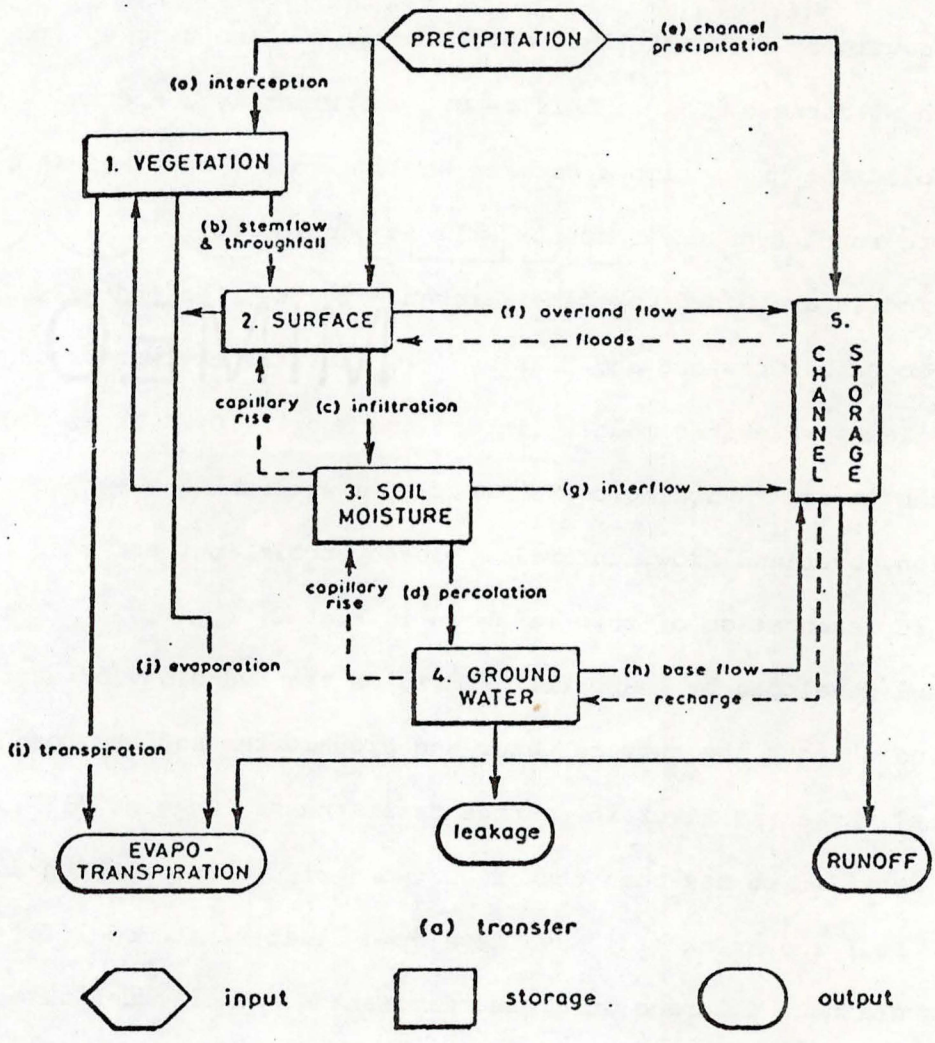


Fig. 2. Watershed Model Scheme.

sediment particles transported in the runoff. Thus a chemical pollutant transport model must be linked to a sediment transport model. A sediment transport model has been developed by Simons and Li (15) at Colorado State University, as discussed in Part 1 of this report.

In the past, a good deal of research has been done on the movement of pollutants on agricultural lands where direct applications of pesticides, herbicides and fertilizers are made to crops. Much of the concepts of this work relating to runoff chemistry could be applicable to highway runoff.

Bailey (16), discusses the idea of "piggybacking" pesticide transport on hydrologic and soil-loss models. The conceptual structure of this overall model includes parameters that determine (i) the initial concentration of pesticides available for runoff, e.g. pesticide formulation, physical-chemical properties and initial distribution, (ii) loss of pesticide from the surface between rainfall events by various attenuation processes (volatilization, microbial, chemical and photochemical degradation and organism uptake) and (iii) loss of pesticide from the soil surface during runoff producing rainfall events because of mass transfer from the soil surface into the moving runoff film and pick up of sediment containing pesticide particulates. This concept is depicted in Figure 3 to illustrate its extreme complexity.

The final and complete version of the ACTMO (Agricultural Chemical Transport Model) developed by Frere (17), appeared in June 1975. The ACTMO model is divided into three submodels; a chemical, an erosional, based on the universal soil loss equation, and a hydrological submodel (USDAHL-74). The erosion submodel receives data from the hydrologic submodel, while the chemical submodel receives data from both the hydrological and erosional submodels. The transport scale is divided into two phases. The first is chemical application, degradation, redistribution by cultivation, nitrate

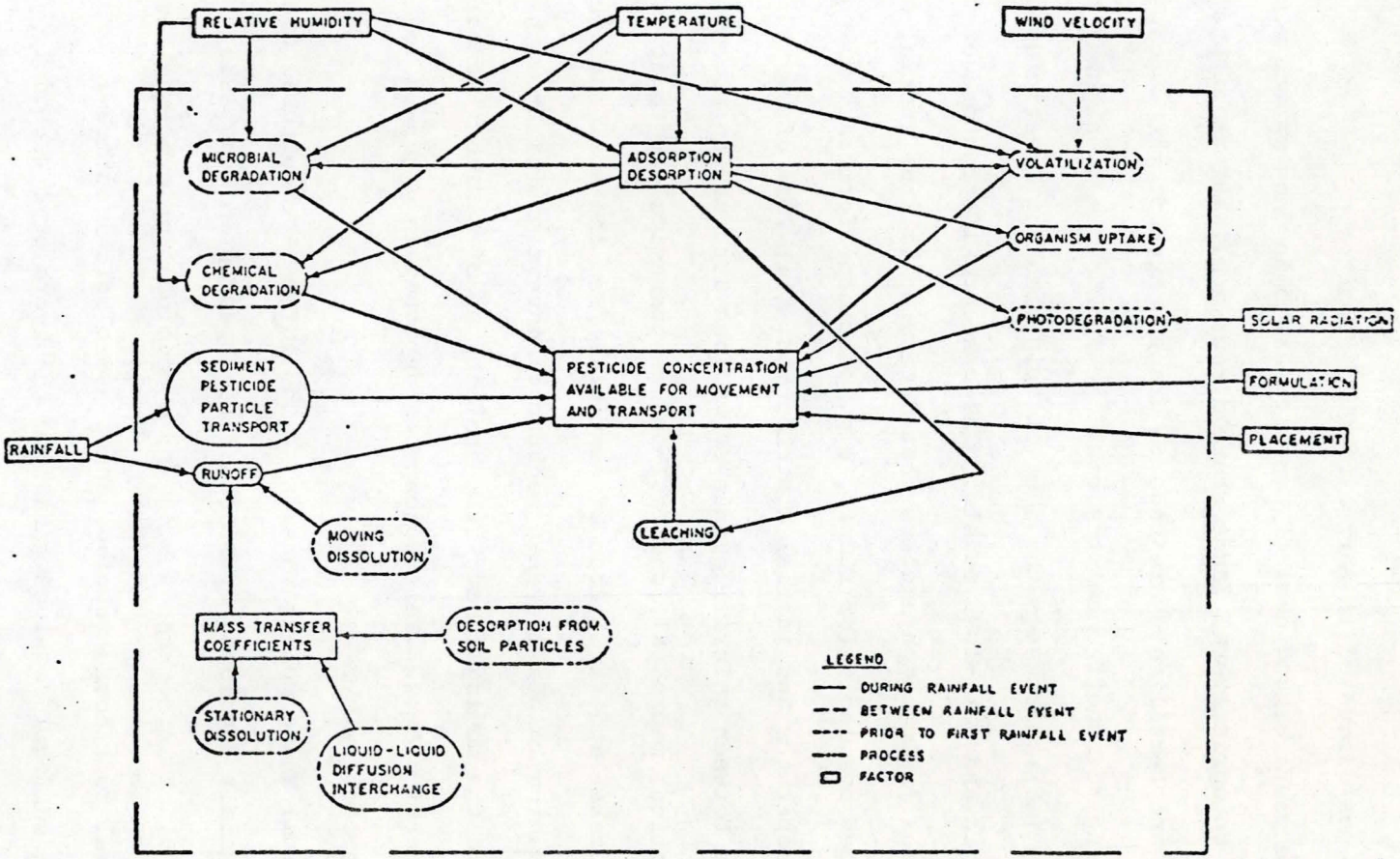


Fig. 3. Processes and Factors Affecting Concentration of Pesticide Available for Runoff from Agricultural Land.

mineralization and uptake by the plants. The second phase is the transportation of chemicals by water and sediment movement. This version is limited to tracing a single application of one chemical at a time. The application of more than one chemical can be handled by repeating the chemical submodel for each chemical. This assumes no interaction between chemicals (a questionable assumption).

The erosion submodel is limited to rill and interrill components of sheet erosion. The hydrology submodel computes average values for evapotranspiration, infiltration and runoff for each zone in the watershed. Only two layers per zone are physically defined and provide useable data. Two other layers are empirically defined as storage from recession flows. The subsurface movement of water laterally from each zone is routed across the alluvium or directly into the channel. Snowmelt is computed in the model for all precipitation increments identified as snow in the input data.

Finally, Caltrans makes reference to a comprehensive mathematical model developed by J. A. Lager et al. which is capable of representing pollutant loadings from urban stormwater runoff. The stormwater management model as it is known, consists of a computer program which simulates real storm events on the basis of rainfall (hydrograph) input and system characterizations (catchment, conveyance, storage--treatment and receiving water) to predict outcomes in the form of hydrographs and pollutographs. The model is subdivided into a main control and service block, called the executive block, and four computational blocks: (a) runoff block, (b) transport block, (c) storage block and (d) receiving block. The quality constituents presently modeled are 5 day biochemical oxygen demand (BOD), total suspended solids, total coliforms and dissolved oxygen.

CONCLUSIONS

The following procedure is envisaged for the implementation of a model developed to simulate water quality changes: Having selected a hydrologic simulation model, whether it be the Stanford or the Kentucky watershed models, it must first be calibrated to accurately predict the runoff over the existing conditions from precipitation events. This calibration stage will determine watershed parameters to be used later in the modeling process. The next stage, is to determine the change in runoff over the existing conditions from precipitation events. This calibration stage will determine watershed parameters to be used later in the modeling process. The next stage, is to determine the change in runoff quantity due to alteration of the watershed by the construction of the highway facility. Various inputs to the model such as watershed canopy, percent of impervious area and change in infiltration rate and stream routing would be adjusted based on the characteristics of the road scheme such as, cleared right-of-way, amount of pavement, composition of soil, and drainage patterns. A sediment submodel could then be applied to the existing and altered situations to determine the effects of the proposed construction on sediment loadings in receiving waters. It would then be necessary to establish the type of maintenance practices to be employed: Will deicing salts, pesticides or herbicides be used? With this information, a chemical submodel could be applied to predict the amount of the surface pollutant that would reach surface and groundwaters and the proportion that would undergo degradation.

It has been established that the basic components of a deterministic model to simulate water quality changes in a watershed do exist within the various disciplines. Efforts must now be aimed at modifying and linking these components parts to form a unified pollutant transport model designed to simulate highway components pollutant impacts on a watershed. Data

availability is a key factor. The Caltrans study is one source of potential data. However, for such a model to be refined and indeed, to be given credibility, thorough testing would have to be carried out on data from a variety of locales.

The experience gained by field testing of the Road Sediment model, ROSED, discussed in Part I of this report, showed that development of a useable sediment model alone, is a formidable goal. A sediment model is envisaged as a subroutine of a larger water quality scheme. Need it to be said that development of a practical water quality predictive model is a tremendously complex task, requiring extensive field studies for test data.

REFERENCES -- PART 1

1. Scheer, A. C. and J. D. Armijo, Transportation System Characteristics Related to Surface Environment and Mining Considerations, Dept. of CE/EM, Montana State University, Bozeman, Montana August, 1975.

2. Armijo, J. D. , E. S.Sundberg and A. C. Scheer, Interim Report on Environmental Effects of Haul Roads, Dept. of CE/EM, Montana State University, Bozeman, Montana July, 1976.

3. Scheer, A. C., E. S. Sundberg and J. D. Armijo, Effects of Mine Haul Roads on the Water Resource, A Progress Report. Dept. of CE/EM, Montana State University, Bozeman, Montana September 1977.

4. Poole, D. R., E. S. Sundberg, J. D. Armijo and A. C. Scheer, Effects of Mine Haul Roads on the Water Resource, User's Guide ROSED, Dept. of CE/EM, Montana State University, Bozeman, Montana July 1978.

5. Wischmeier, W. H. and L. D. Myer. Soil Erodibility on Construction Areas, Highway Research Special Report 135: 20-29, 1973.

6. Wischmeier, W. H. and D. D. Smith, Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains, USDA Agr. Handbook 282, 1965.

7. Wischmeier, W. H., C. B. Johnson and B. V. Cross, A Soil Erodibility Monograph for Farmland and Construction Site, Journ. Soil. and Water Conserv. 26: 189-193, 1971.

8. Foster, G. R. and W. H. Wischmeier, Evaluating Irregular Slopes for Soil Loss Prediction, Trans. ASAE 17: 305-309, 1974.

9. Utah Water Research Laboratory, Erosion Control During Highway Construction, prepared tor Transportation Research Board, Utah State Univ., Logan, 1975.

10. Ports, M. C., Chief of Surface Water Permits, State of Maryland, Water Resources Admin. Personal communication, Lexington, KY, July 1976.

11. Meyer, L. D. and M. C. Ports. Prediction and Control of Urban Erosion and Sedimentation, Nat. Symp. on Urban Hydrol, Hydraulics and Sediment Control, Lexington, KY July 1976.

12. Howell, R. B., Highway Slope Erosion Transect Surveys, Water Quality Manual, Vol. III, Calif. Dept. of Transp. Sacramento, CA 1973.

13. Poche, D. J., A Design Program for the Estimation and Abatement of Soil Losses from Highway Slopes, Virginia Highway Research Council, Charlottesville, VA 1974.

14. Sultan, A. S. and P. Fleming. Soil Erosion and Dust Control on Arizona Highways, Part I, State of the Art Review, Arizona Dept. of Transp. 1974.

15. Swerdon, P. M. and R. R. Kountz. Sediment Runoff Control at Highway Construction Sites, Engr. Res. Bul. B-108, Penn State Univ., Univ. Park, PA, 1973.

16. Younkin, L. M., Prediction of the Increase in Suspended Sediment Transport due to Highway Construction, Interim Report, Dept. of Civil Engr., Bucknell Univ., Lewisburg, PA. 1977.

17. Miller, Art, Personal communications concerning sedimentation research at Penn State University, Univ. Park, PA 1976-77.

18. Simons, D. B., R. M. Li, and L. Y. Shiao, Formulation of Road Sediment Model. Report to Rocky Mt. Forest and Range Experiment Station, Flagstaff, Arizona, 1977.

19. Shiao, L. Y., Summary - Rainfall Simulator Conference, Alamosa, Colorado, June 19-20, 1978. reported to participants in memo from E. L. Neff, Northern Plains Soil and Water Research Center, Sidney, Montana July 13, 1978.

20. Neff, E. L. Simulator activities - Sidney, Montana. Proc. Rainfall Simulator Workshop, Tucson, Arizona. USDA, SEA, Ag. Reviews and Manuals. ARM-W-10/July 1979.

21. Simons, D. B., R. M. Li, and T. J. Ward. 1977. "Simple Procedural Method for Estimating On-Site Soil Erosion", Civil Engineering Dept., Engineering Research Center, Colorado State University, Ft. Collins, CO CER 76-77DB5-RML-TJW38, 55 pp., February 1977.

22. Simons, D. B., R. M. Li, T. J. Ward, and K. G. Eggert. 1979. "Estimation of Input Parameters for Modeling of Water and Sediment Yields", Ft. Collins, CO. CER 78-70DB5-RML-TJW-KGE50, 56 pp., April 1979.

23. Simons, D. B., R. M. Li, and L. Y. Shiao, 1976. "Preliminary Procedural Guide for Estimating Water and Sediment Yield from Roads in Forests, " Civil Engineering Dept., Engineering Research Center, Colorado State University, Ft. Collins, CO CER76-77DBS-RML-LYS21, 120 pp., November 1976.

24. Agricultural Research Service, "Control of Water Pollution from Cropland, Volume I., A Manual for Guideline Development", Office of Research and Development, Environmental Protection Agency, November 1975.

REFERENCES -- PART 2

1. Sylvester, R. O., F. O. DeWalle, "Character and Significance of Highway Runoff Waters", Washington State Highway Commission, Report No. 7.1, Nov. 1972.

2. Soderlund, G., et al., "Physiochemical and Microbiological Properties of Urban Storm Water Runoff." Proc. 5th Intern. Water Pollut. Research Conf. July, 1970, New York.

3. Dalseg, R. D., and Farris, G. D., "The Quality of Rainfall Runoff From Interstate 5 at Seattle," Municipality of Metropolitan Seattle. (April 16, 1970).

4. Howell, R. B. "Water Pollution Aspects of Particles Which Collect On Highway Surfaces," Caltrans Report No. FHWA--CA--TL-77-22, July 1978.

5. Shaheen, D. G. "Contributions of Urban Roadway Usage to Water Pollution," Environmental Protection Agency Technology Series Report 600/2-75-004.

6. "Storm Water Pollution From Urban Land Activity," by AVCO Economic Systems Corporation, Water Pollution Control Research Series, No. 11034 FKL 07/70.

7. Pravoshinsky, N. A., and Gatillo, P. D., "Determination of the Pollutional Effect of Surface Runoff." Proc. 4th Int. Conf. on Water Pollution Research, Prague, 1969.

8. Crawford, N. H., and R. K. Linsley, "Digital Simulation in Hydrology: Stanford Watershed Model iv." Stanford University, Dept. of Civil Engineering, Technological Report No. 39. (July 1966).

9. James, L. D. An Evaluation of Relationships Between Streamflow Patterns and Watershed Characteristics Through the Use of OPSET (A self calibrating version of the Stanford Watershed Model), University of Kentucky, Water Resources Institute Research Report No. 30. (1970).

10. Moore, W. L., and Claborn, B. J., "Numerical Simulation of Watershed Hydrology," University of Texas at Austin, Dept. of Civil Eng. (August, 1970).

11. Knapp, R. M., et al. "Generalized Computer Model To Simulate The Hydrology of a Stream Basin," Watersheds in Transition, American Water Resources Association and Colorado State University. (1972).

12. Huggins, L. E., et al. "Simulation of the Hydrology of Ungaged Watersheds." Purdue University, Water Research Centre Technical Report No. 38 (June, 1973).

13. Leaf, C. F. and Brink, G. E., "Hydrologic Simulation Model of a Colorado Subalpine Forest," U.S.D.A. Forest Service Research Paper (May 1973).

14. Patterson, M. R., et al. "A Users Manual for the Fortran IV version of the Wisconsin Hydrologic Transport Model." Oak Ridge National Laboratory. (ORNL-NSF-EATC-7, EDFB-1BP-74-9). Oak Ridge, TN.

References Part 2 (Cont.)

15. Simons, D. B., Li, R. M., and Shiao, L. Y., "Formulation of Road Sediment Model," Report to Rocky Mountain Forest and Range Experiment Station, Flagstaff, AZ 1977.

16. Bailey, et al., "Predicting Pesticide Runoff from Agricultural Land: A Conceptual Model". Journal of Environmental Quality, Vol. 3, No. 2, 1974.

17. Frere, M. H., "Integrating Chemical Factors With Water and Sediment Transport from a Watershed," Journal of Environmental Quality, Vol. 4, No. 1, (January - March 1975).

APPENDIX

The following pages contain graphical representations of data collected from all of the rainfall-on-roadway simulations. Data represented are as follows:

I. Actual rainfall vs observed runoff

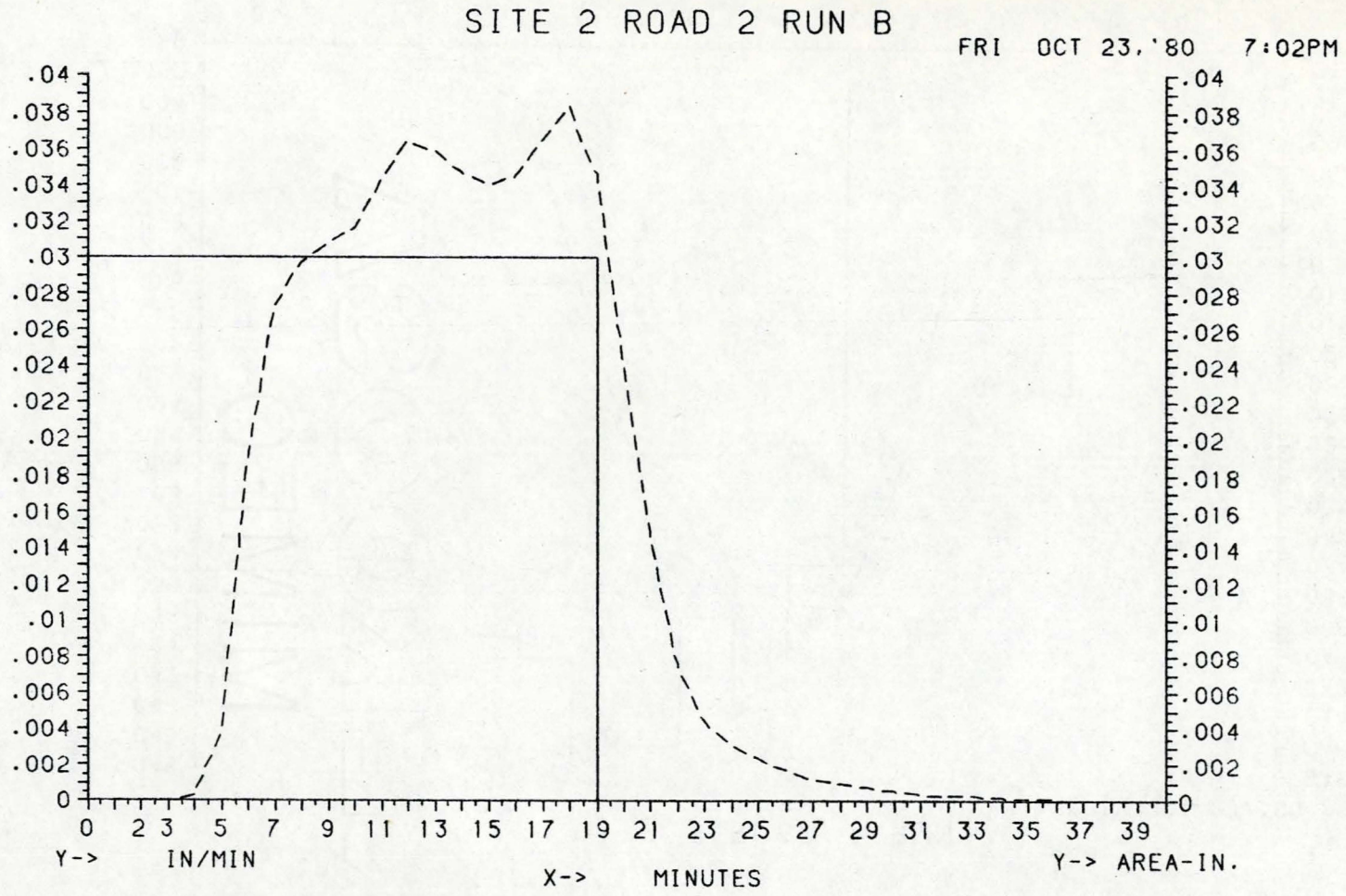
II. Actual runoff vs sediment production

III. Actual runoff vs predicted runoff

IV. Actual sediment vs predicted sediment

V. Predicted runoff vs predicted sediment

The digitizing method, the user-interactive computer system that was used to graphically show the data, is not given in this report. The lengthy Fortran IV programs, DIGIT and GRAF, were developed for use in this study and are documented in a paper entitled Data Display System by Mackley F. Pexton, for Dept. of Civil Engineering and Engineering Mechanics, Montana State University, Sept. 1979.


SITE 2 ROAD 2 RUN B
FRI OCT 23,'80 7:02PM
.04
.038
.036
.034
.032
.03
.028
.026
.024
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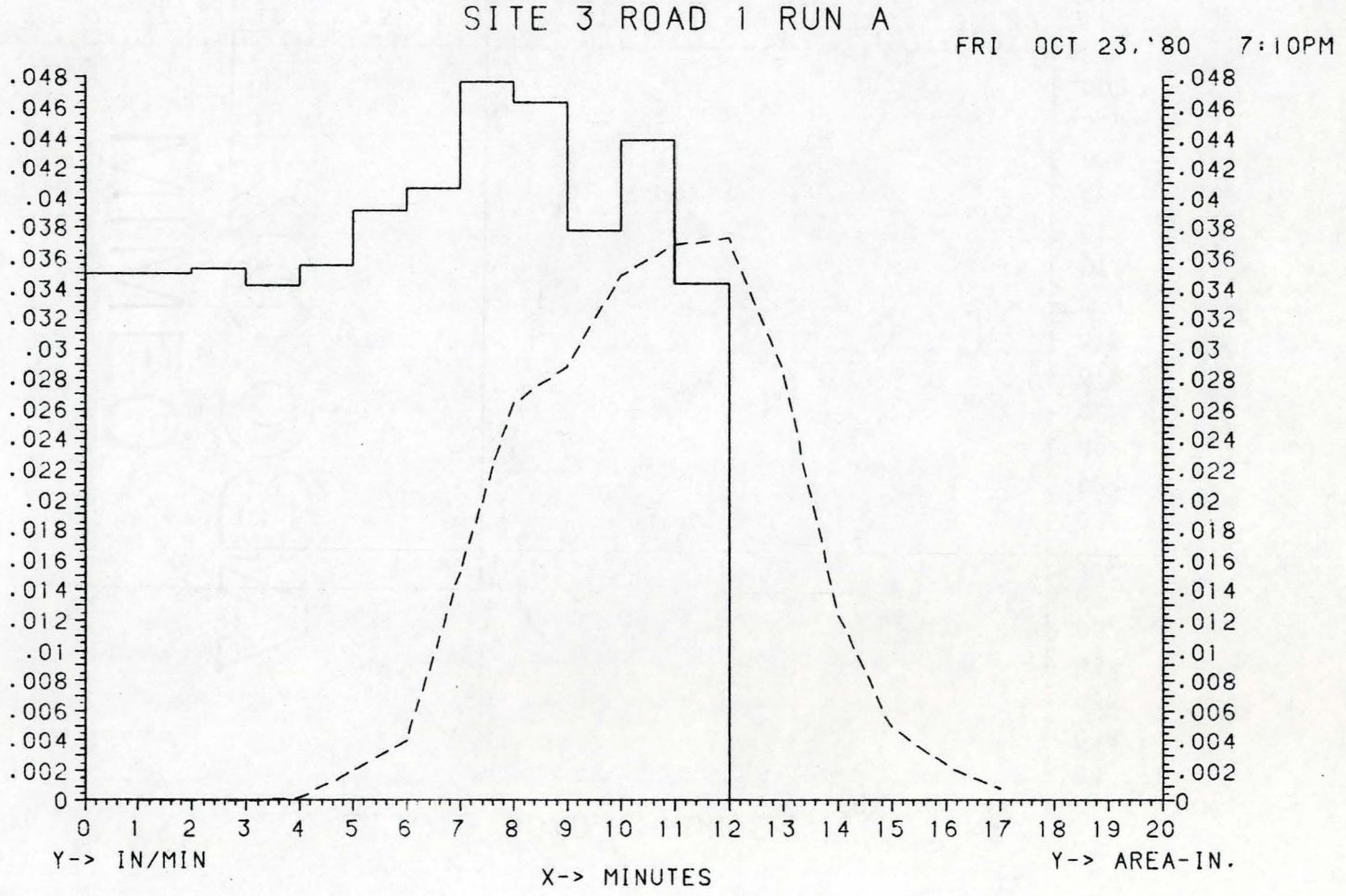
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 2 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39
Y-> IN/MIN
X-> MINUTES
Y-> AREA-IN.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.026
.024
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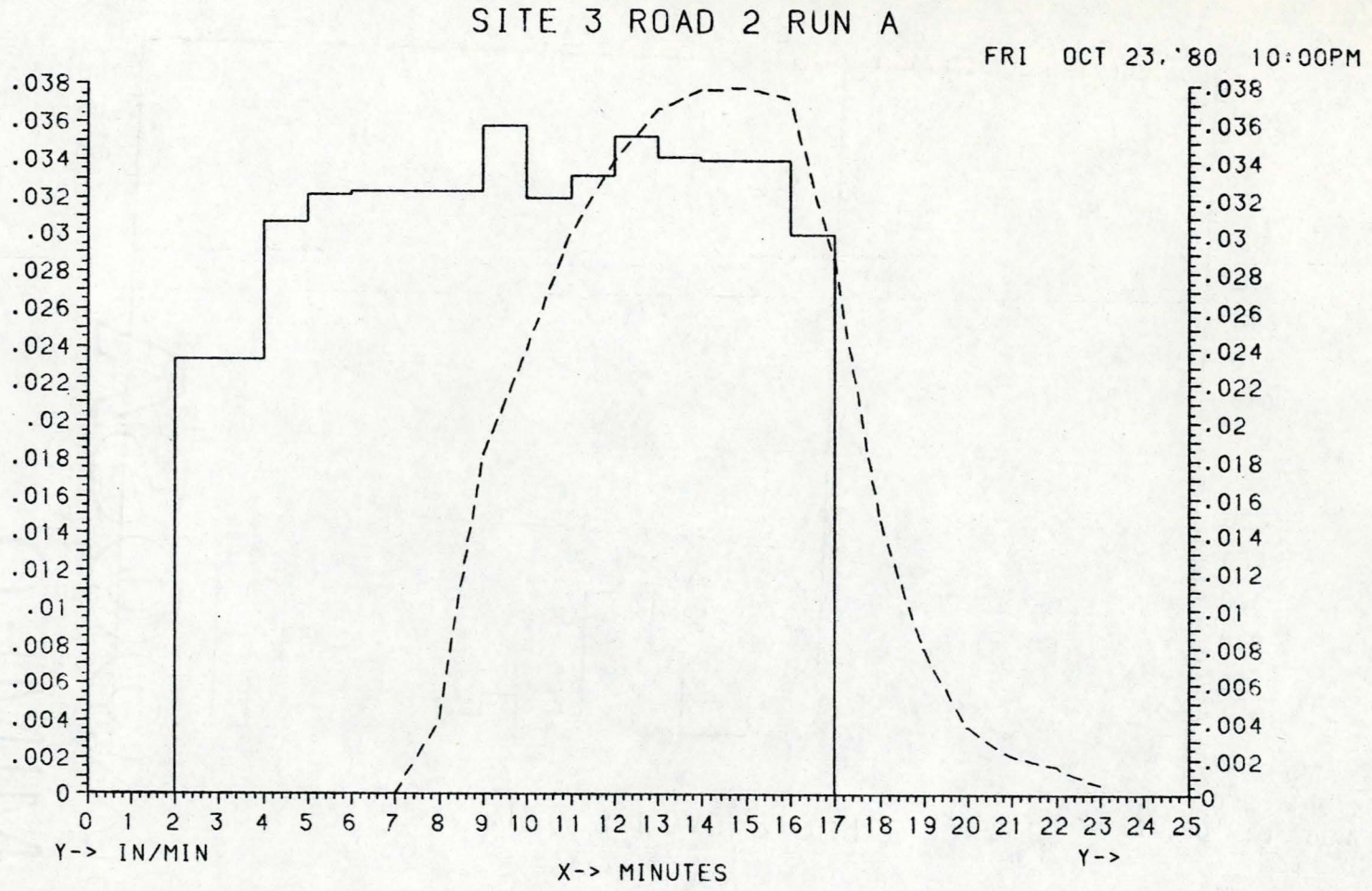
.016
.014
.012
.01
.008
.006
.004
.002
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Y-> IN/MIN
X-> MINUTES
Y-> AREA-IN.


SITE 3 ROAD 2 RUN A
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.024
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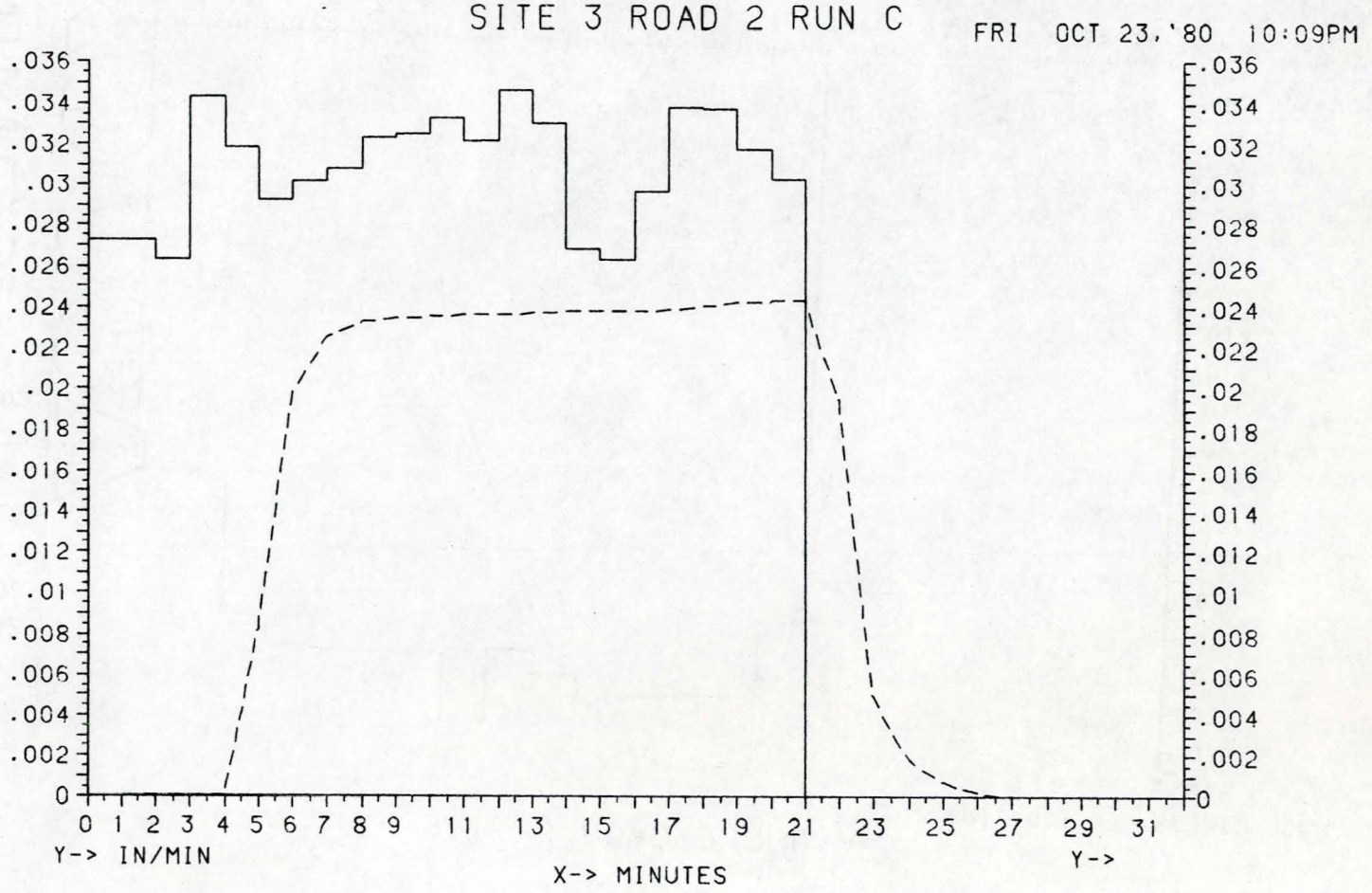
.016
.014
.012
.01
.008
.006
.004
.002
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Y-> IN/MIN
X-> MINUTES
Y->


SITE 3 ROAD 2 RUN C
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.03
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.022
.02
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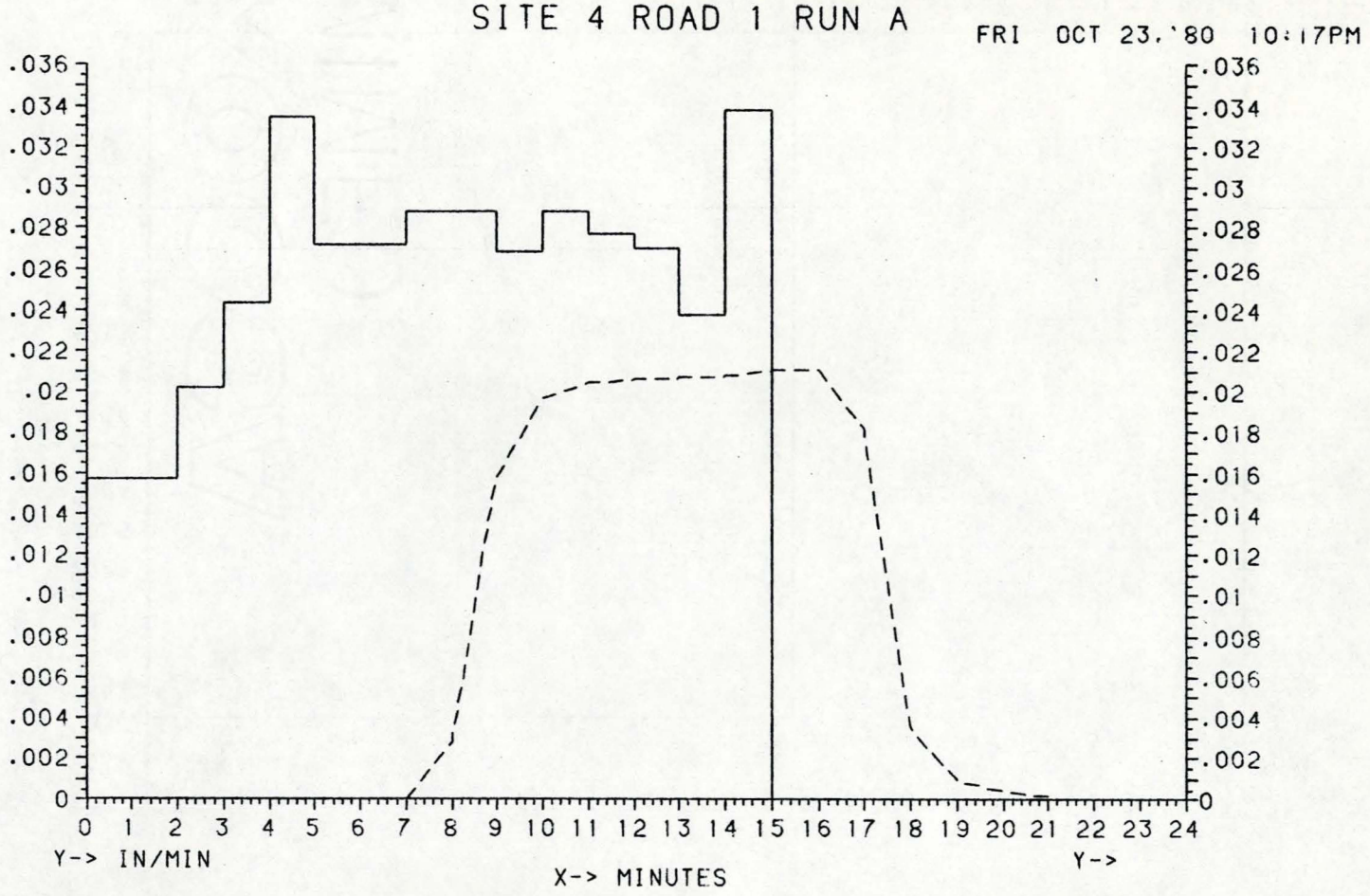
.016
.014
.012
.01
.008
.006
.004
.002
0
0 1 2 3 4 5 6 7 8 9 11 13 15 17 19 21 23 25 27 29 31
Y-> IN/MIN
X-> MINUTES
Y->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.014
.012
.01
.008
.006
.004
.002
0
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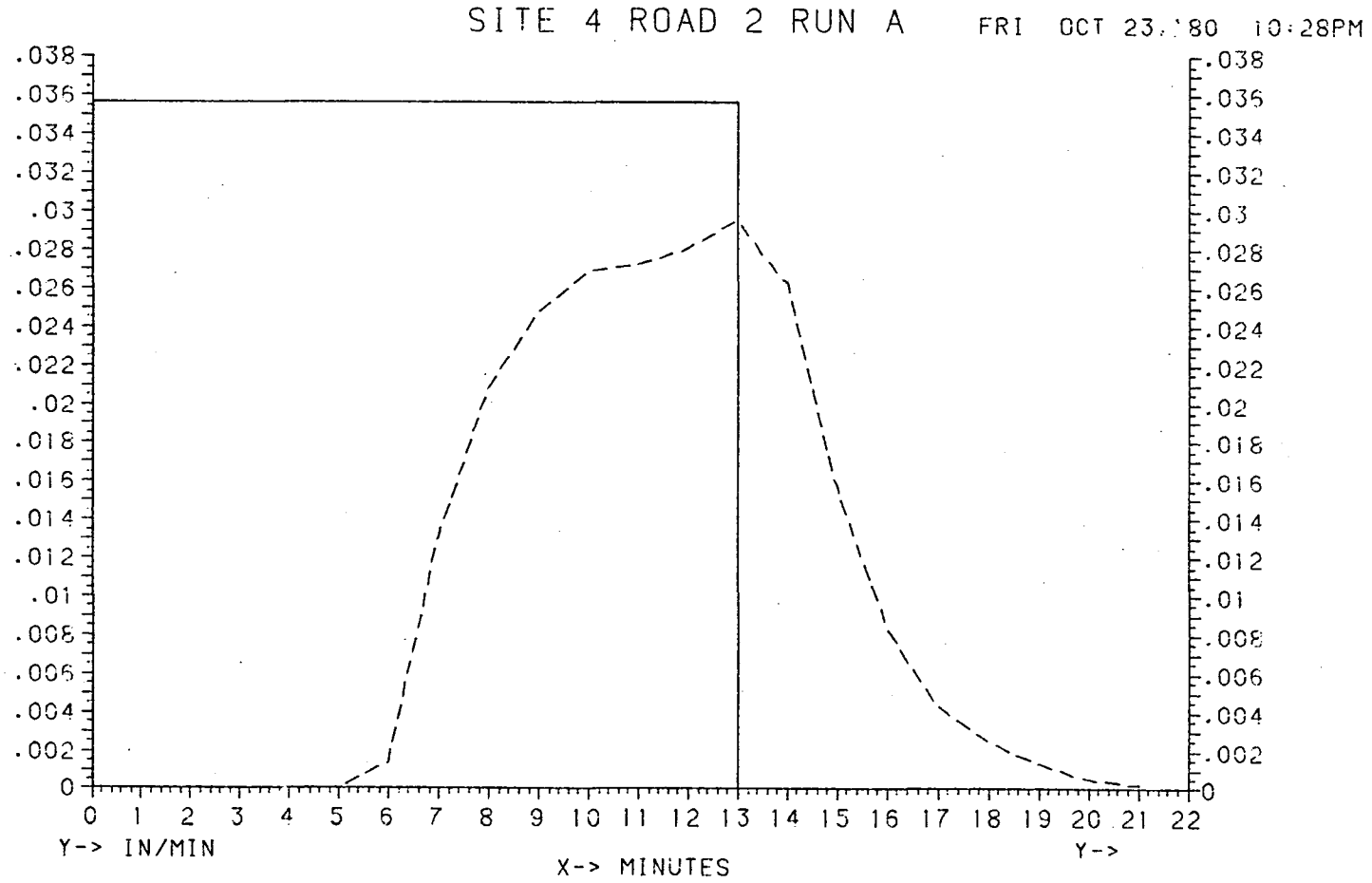
Y-> IN/MIN
X-> MINUTES
Y->


SITE 4 ROAD 2 RUN A
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.036
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.032
.03
.028
.026
.024
.022
.02
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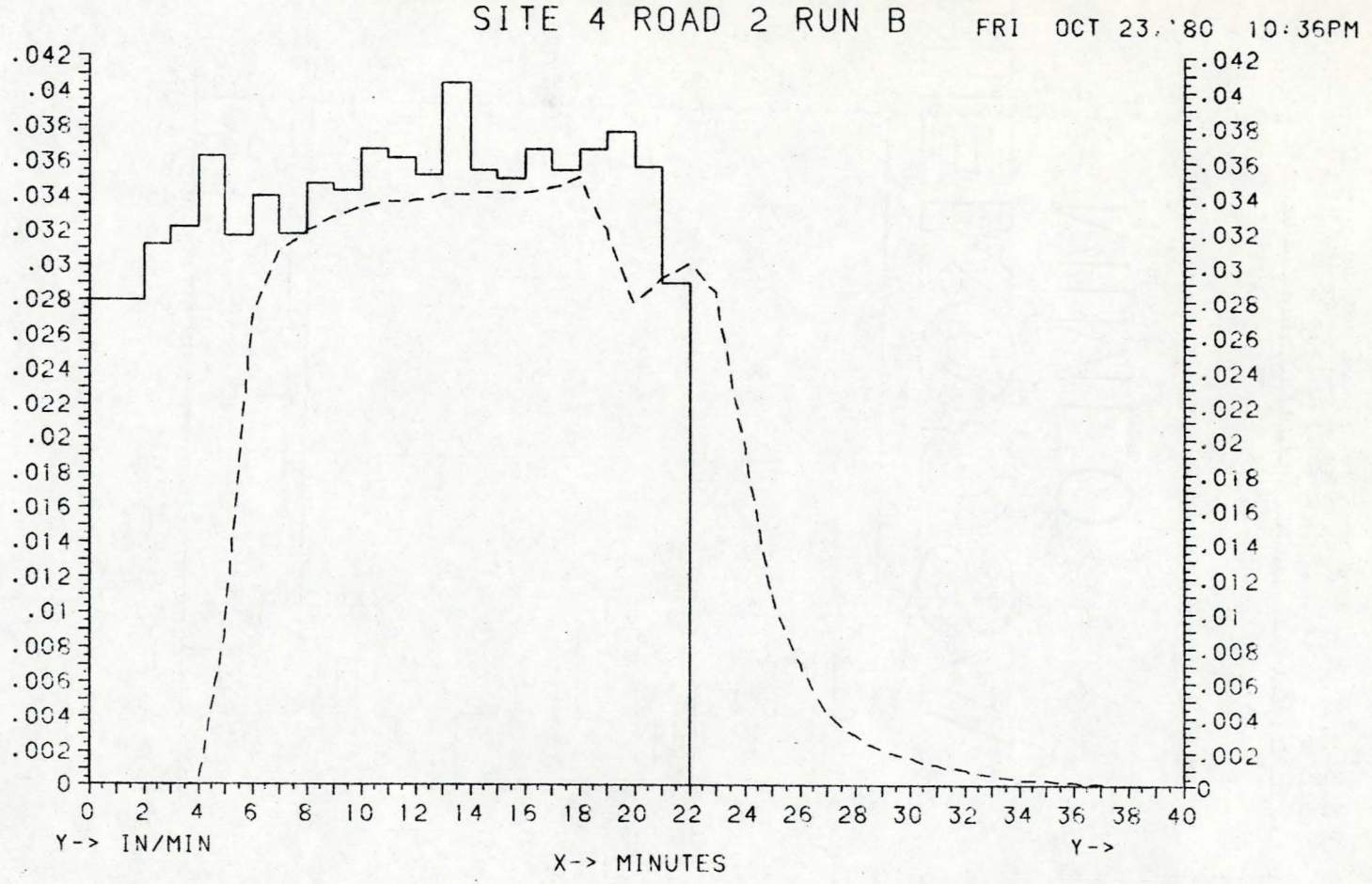
.014
.012
.01
.008
.006
.004
.002
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Y-> IN/MIN
X-> MINUTES
Y->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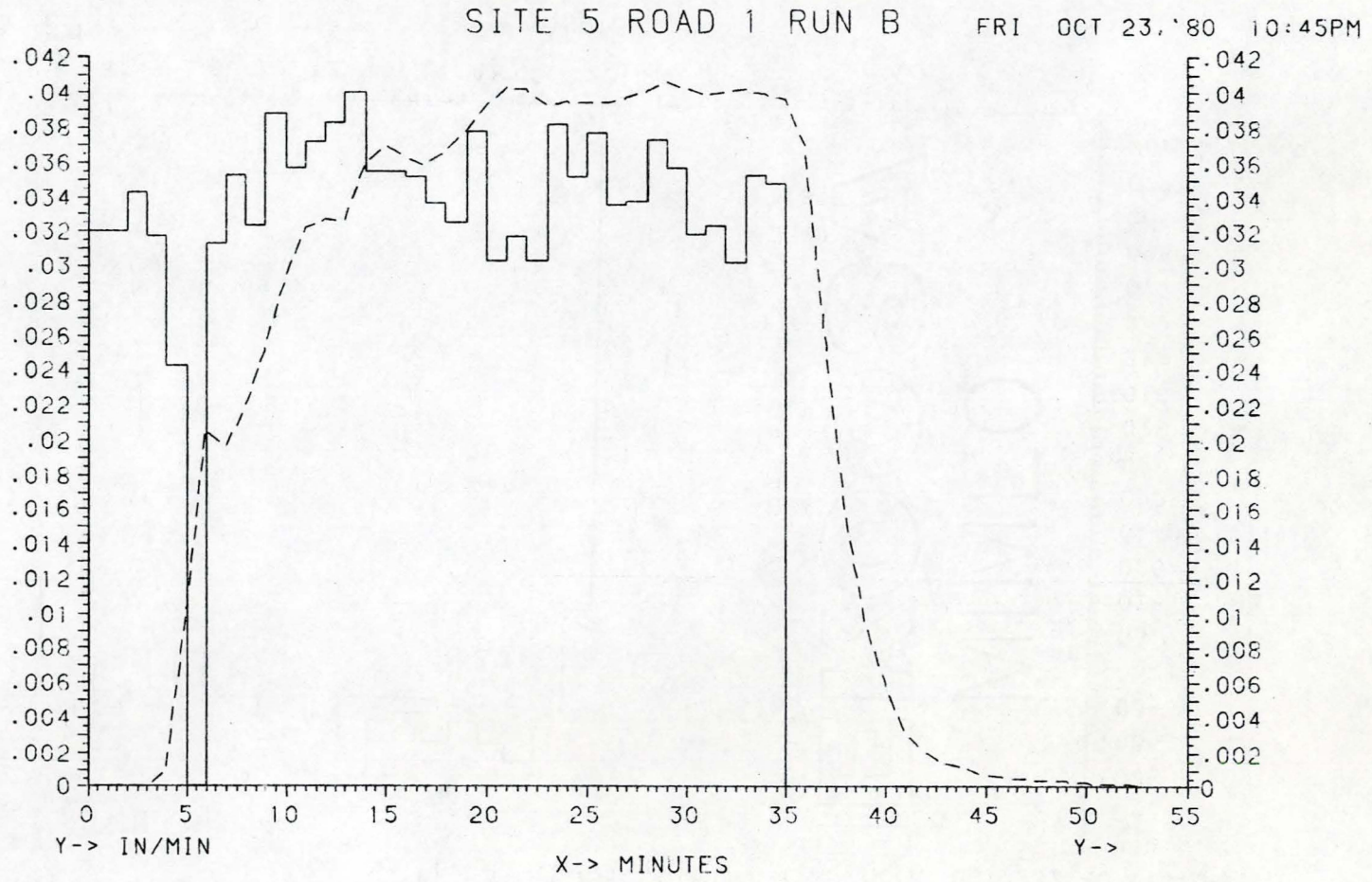
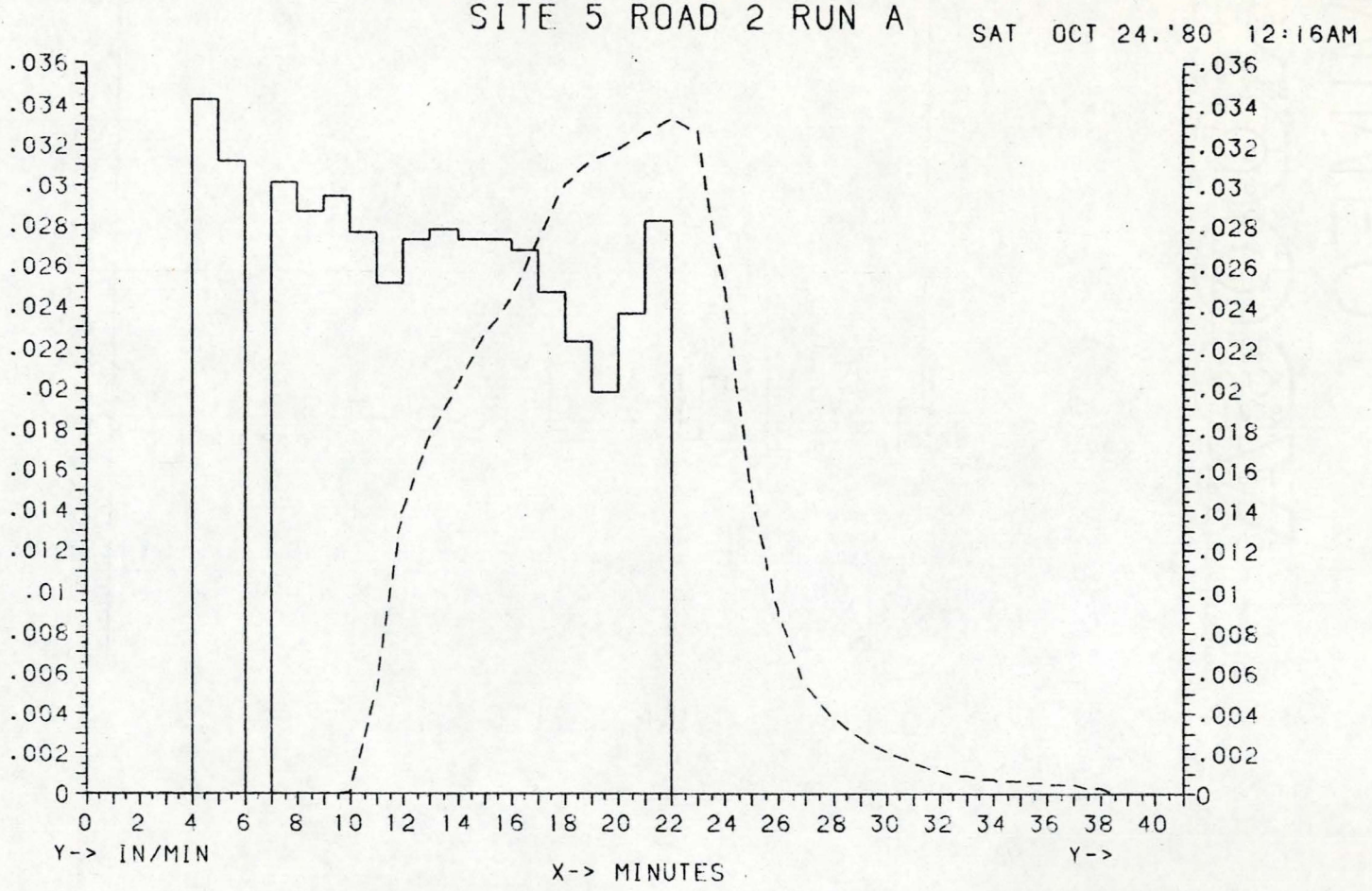
.04
.038
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Y-> IN/MIN
X-> MINUTES
Y->


SITE 5 ROAD 1 RUN B
FRI OCT 23,'80 10:45PM
.042
.04
.038
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 5 10 15 20 25 30 35 40 45 50 55
Y-> IN/MIN
X-> MINUTES
Y->


SITE 5 ROAD 2 RUN A
SAT OCT 24,'80 12:16AM
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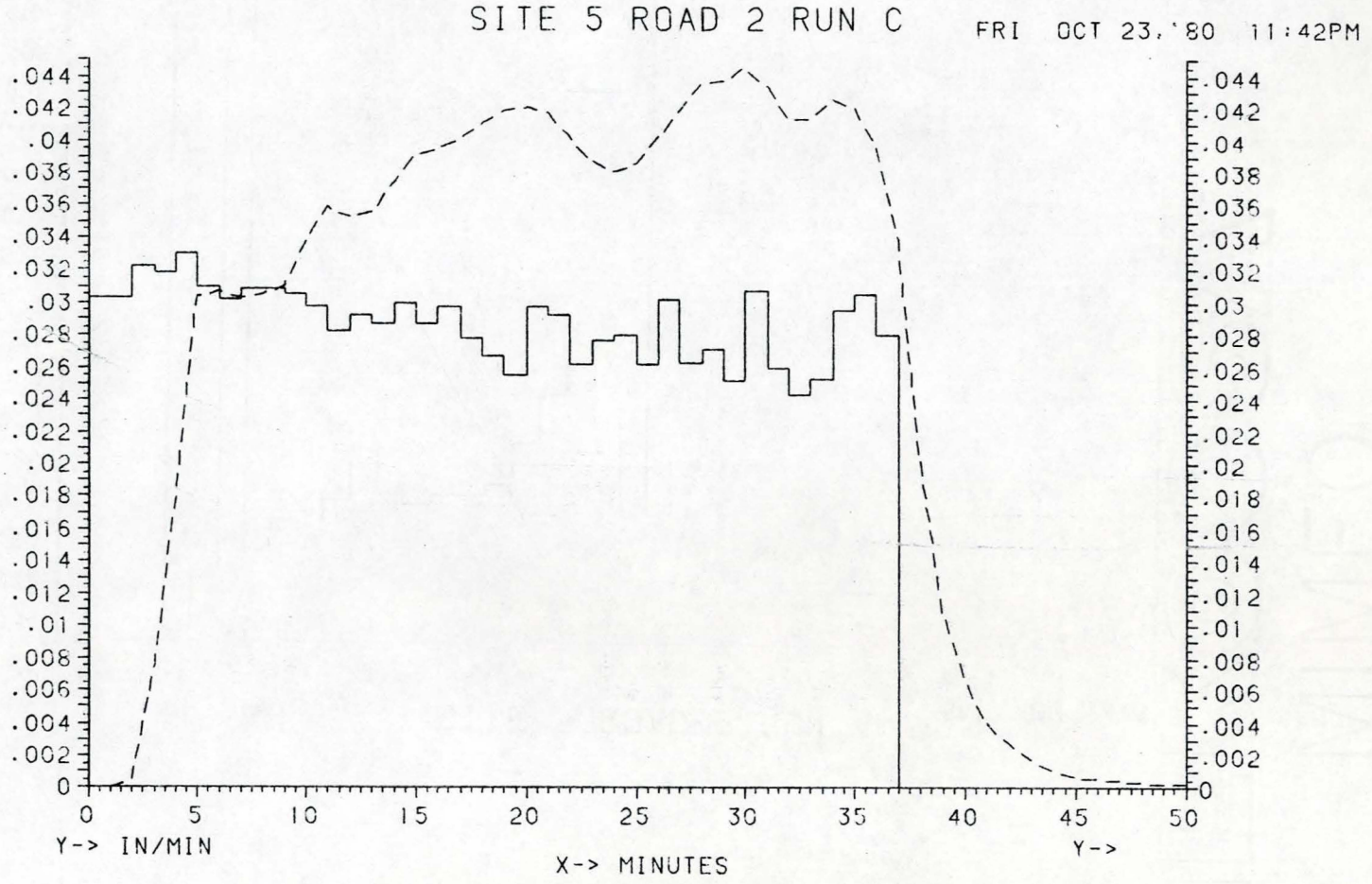
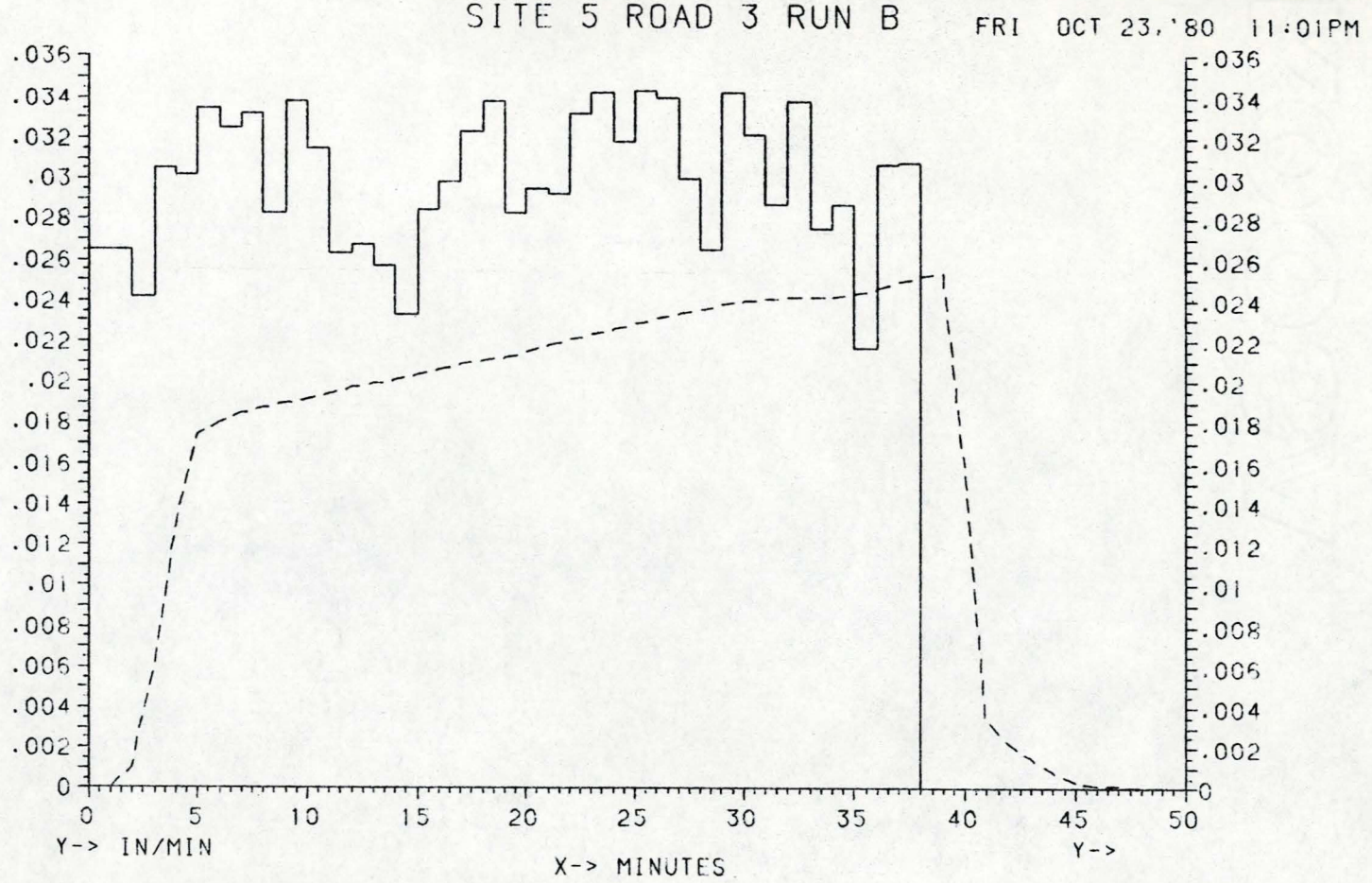
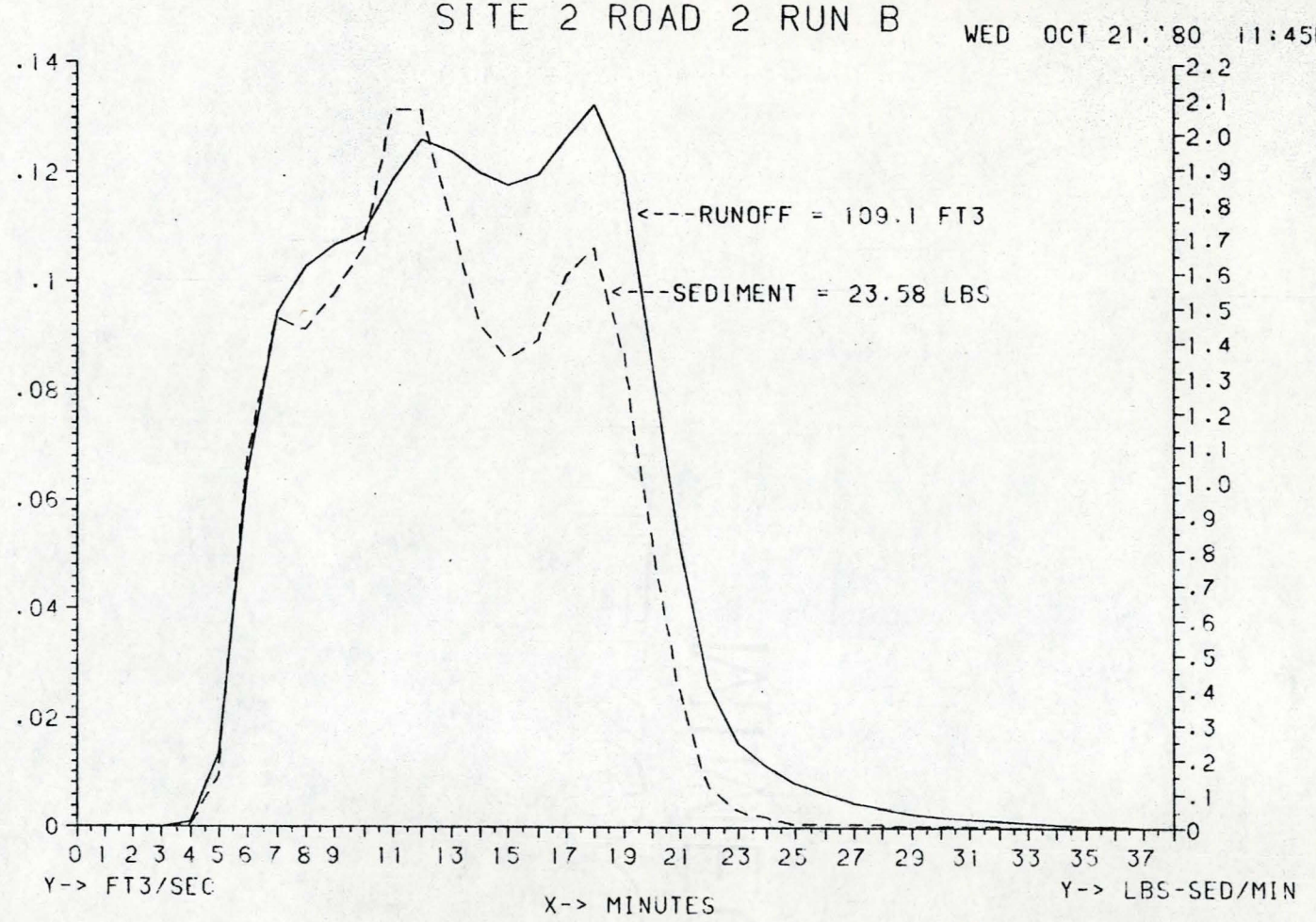
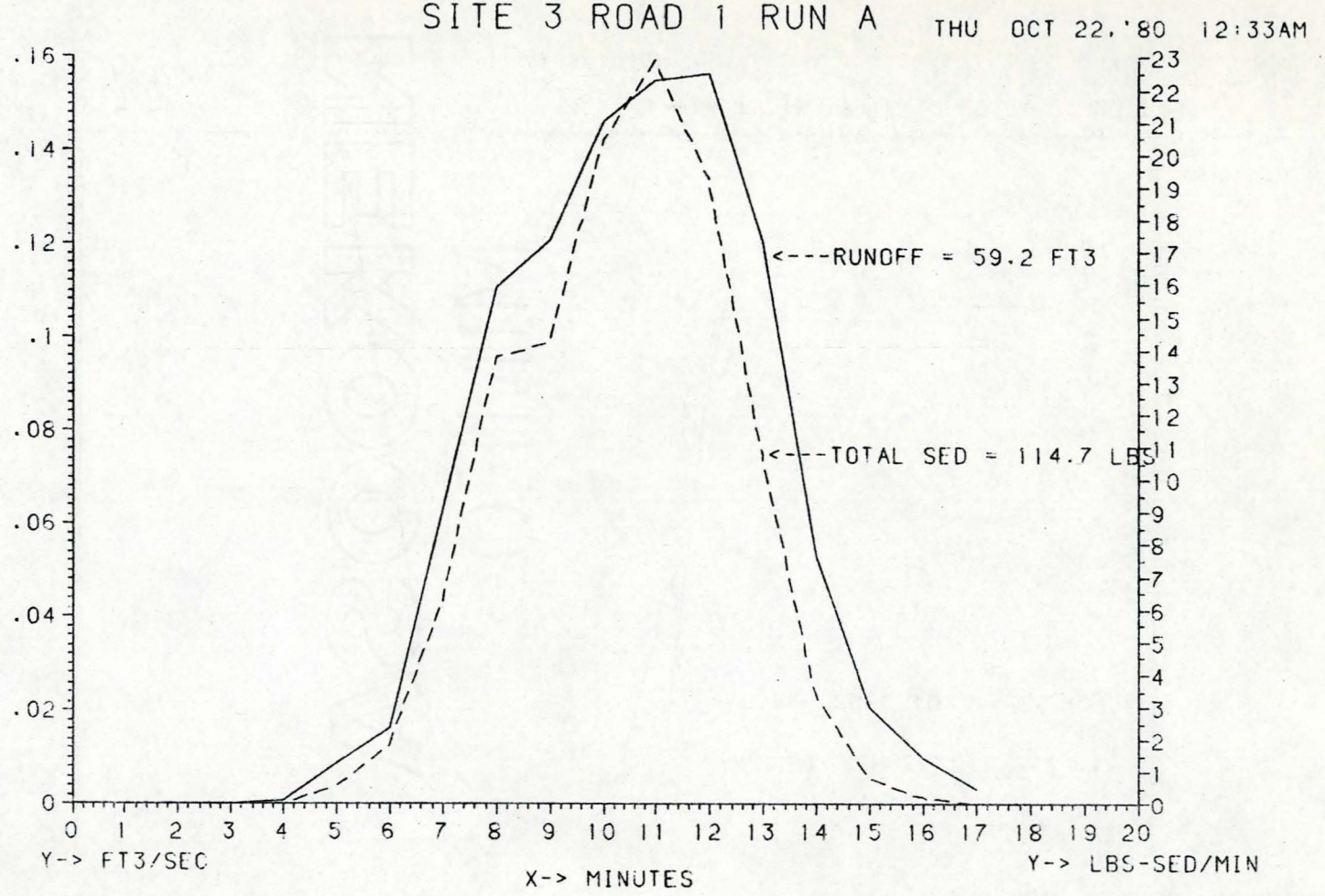
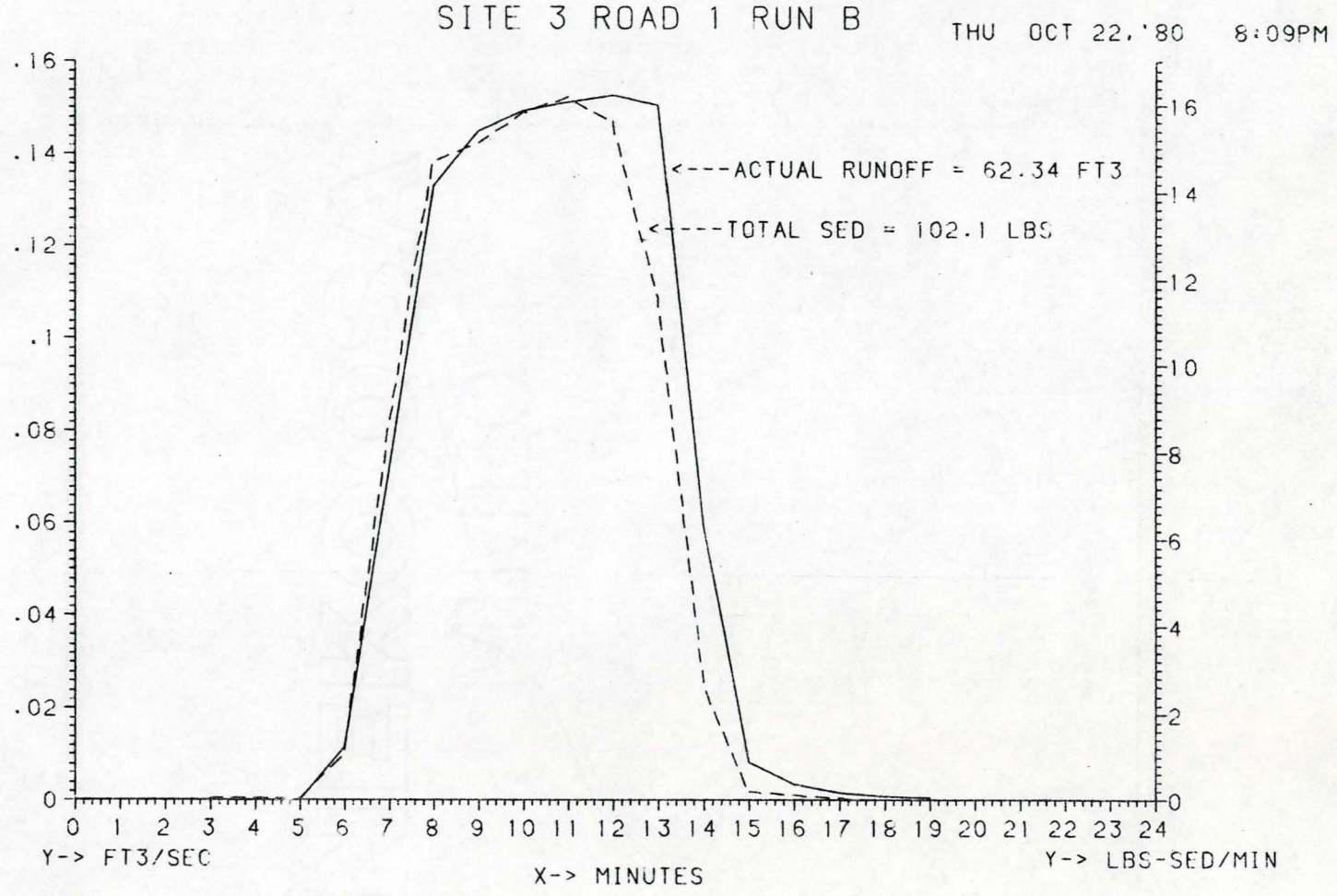
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Y-> IN/MIN
X-> MINUTES
Y->

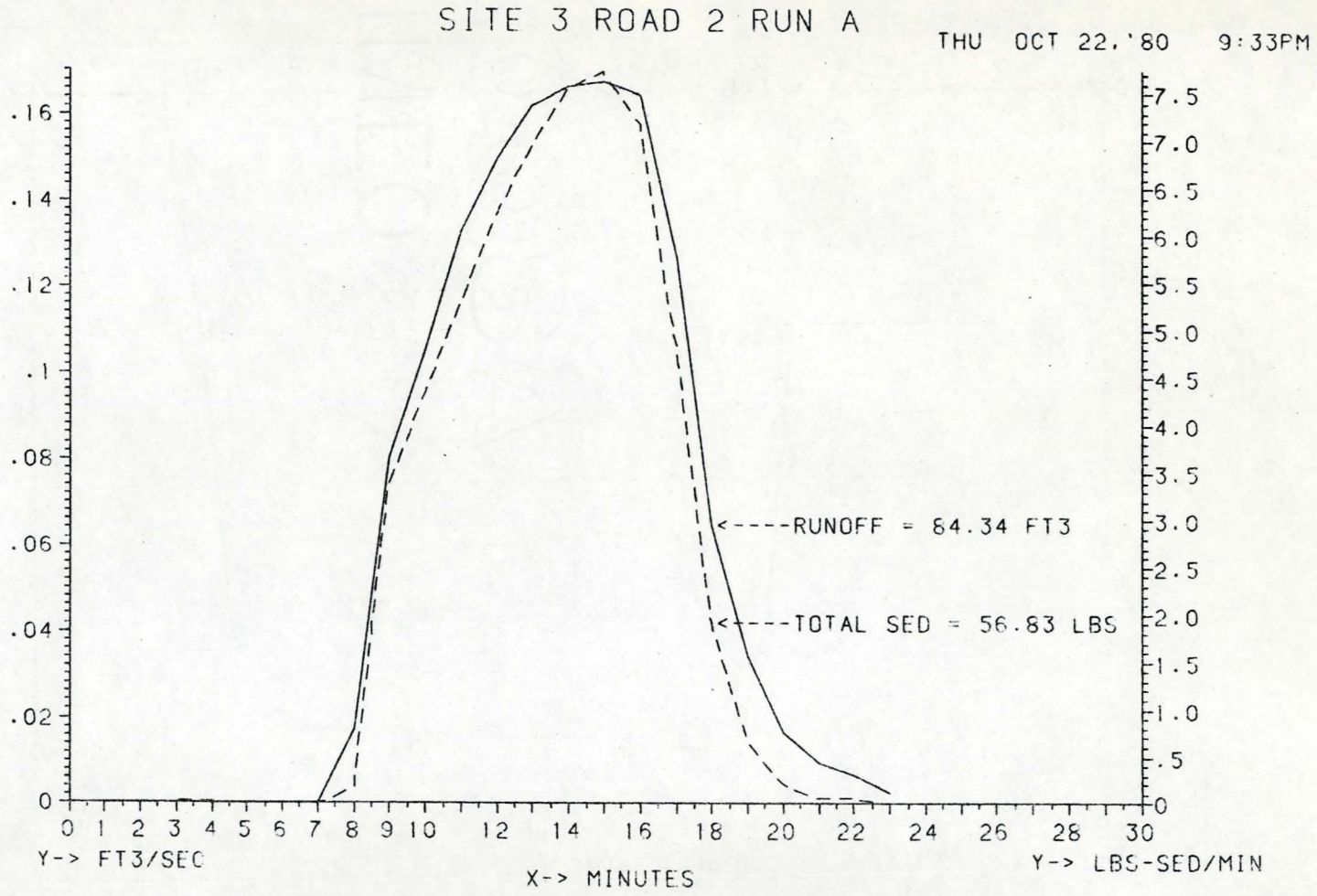

SITE 5 ROAD 2 RUN C
FRI OCT 23,'80 11:42PM
.044
.042
.04
.038
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 5 10 15 20 25 30 35 40 45 50
Y-> IN/MIN
X-> MINUTES
Y->

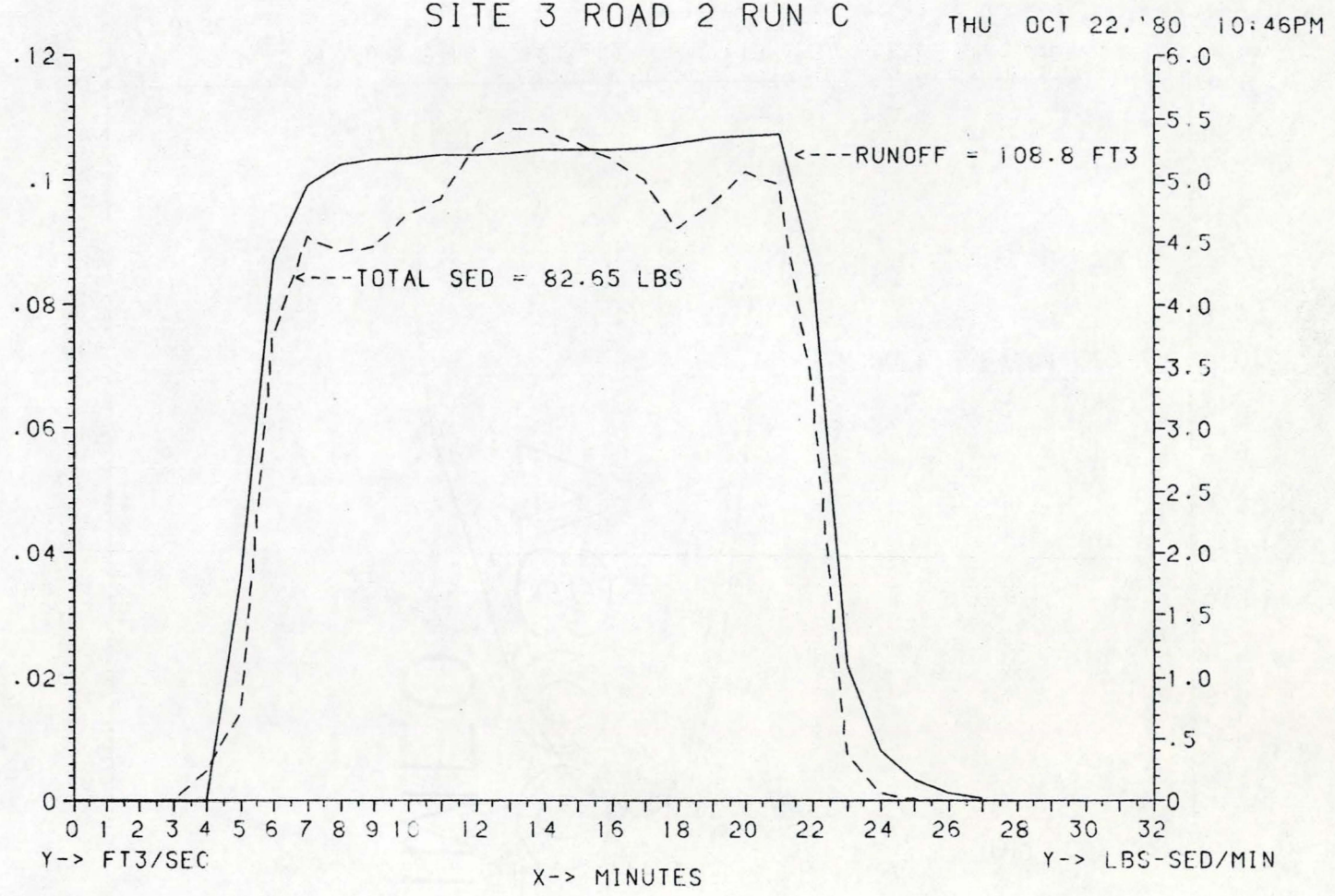

SITE 5 ROAD 3 RUN B
FRI OCT 23,'80 11:01PM
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 5 10 15 20 25 30 35 40 45 50
Y-> IN/MIN
X-> MINUTES
Y->

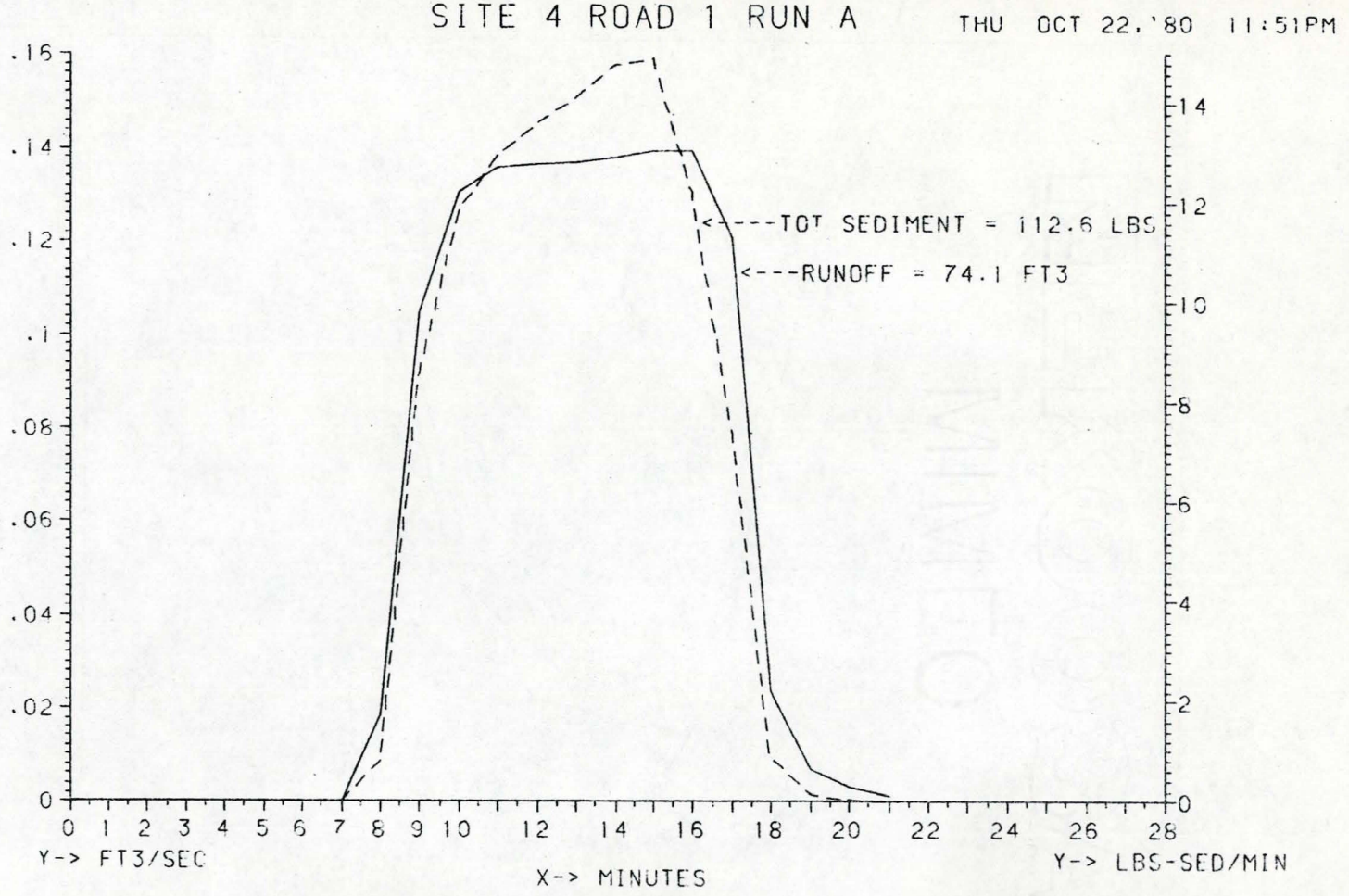

SITE 2 ROAD 2 RUN B
WED OCT 21,'80 11:45PM
<---RUNOFF = 109.1 FT3
<---SEDIMENT = 23.58 LBS
.14
.12
.1
.08
.06
.04
.02
0
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0 1 2 3 4 5 6 7 8 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

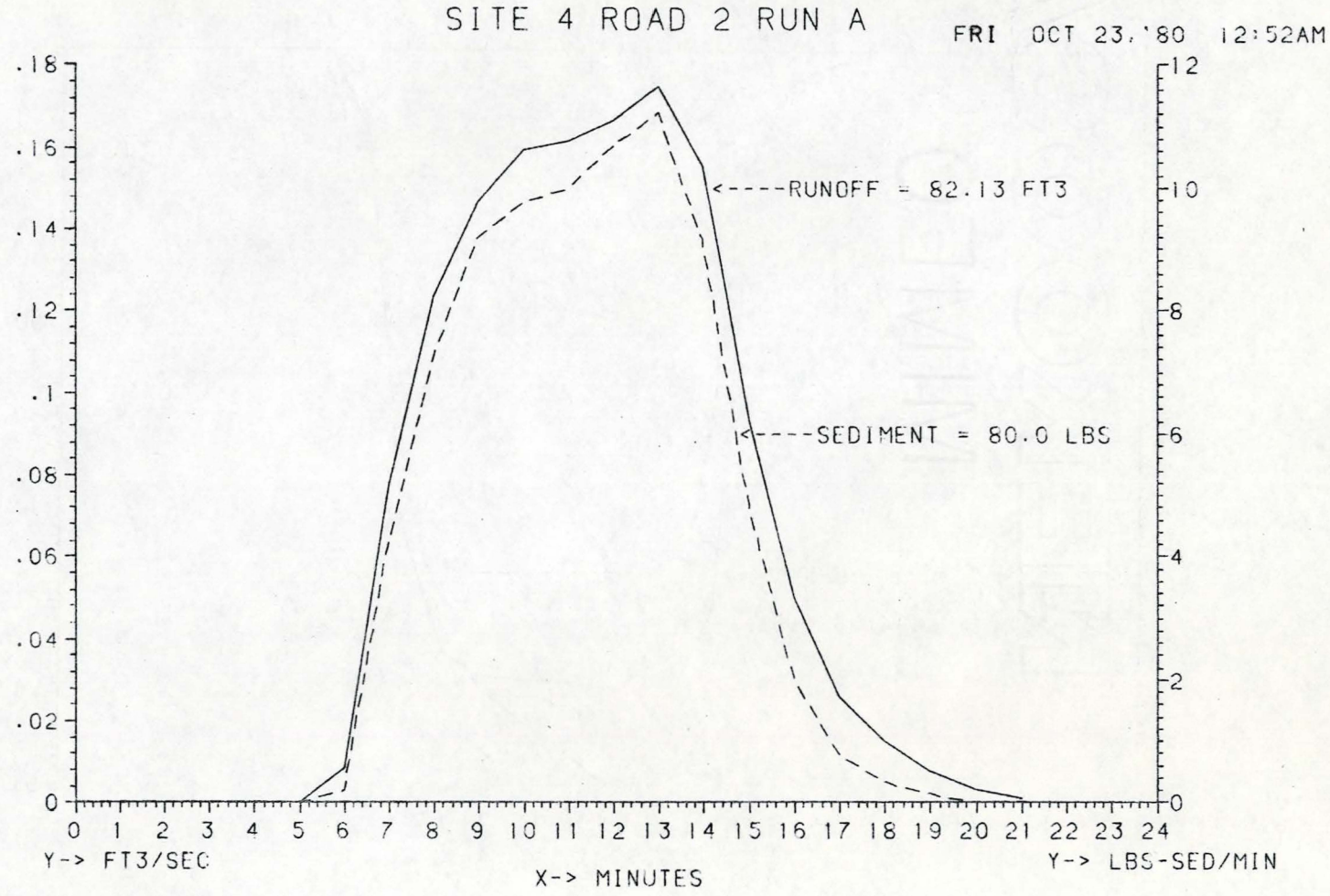

SITE 3 ROAD 1 RUN A
THU OCT 22,'80 12:33AM
<---RUNOFF = 59.2 FT3
<---TOTAL SED = 114.7 LBS
.16
.14
.12
.1
.08
.06
.04
.02
0
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

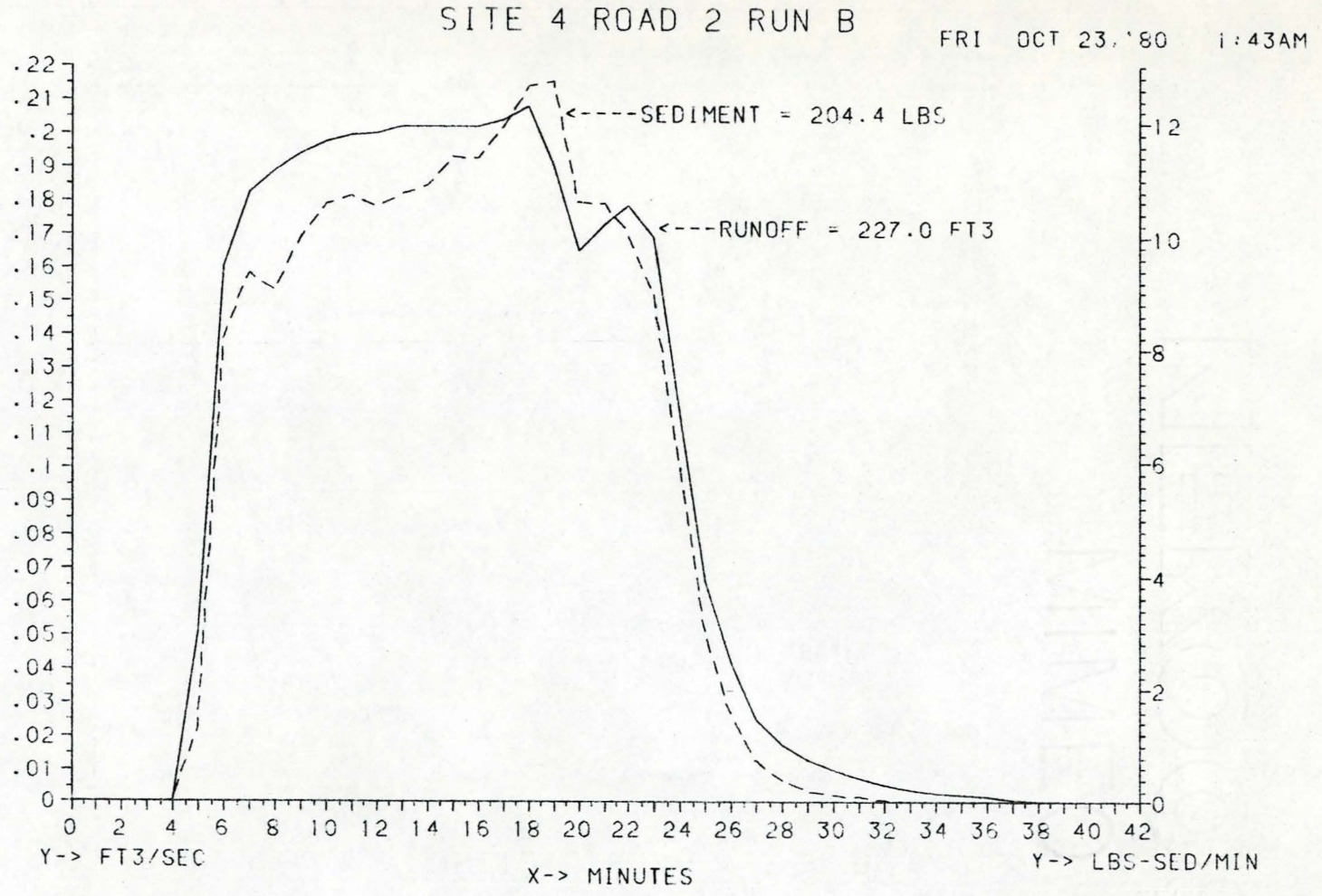

SITE 3 ROAD 1 RUN B
THU OCT 22,'80 8:09PM
<---ACTUAL RUNOFF = 62.34 FT3
<---TOTAL SED = 102.1 LBS
.16
.14
.12
.1
.08
.06
.04
.02
0
16
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

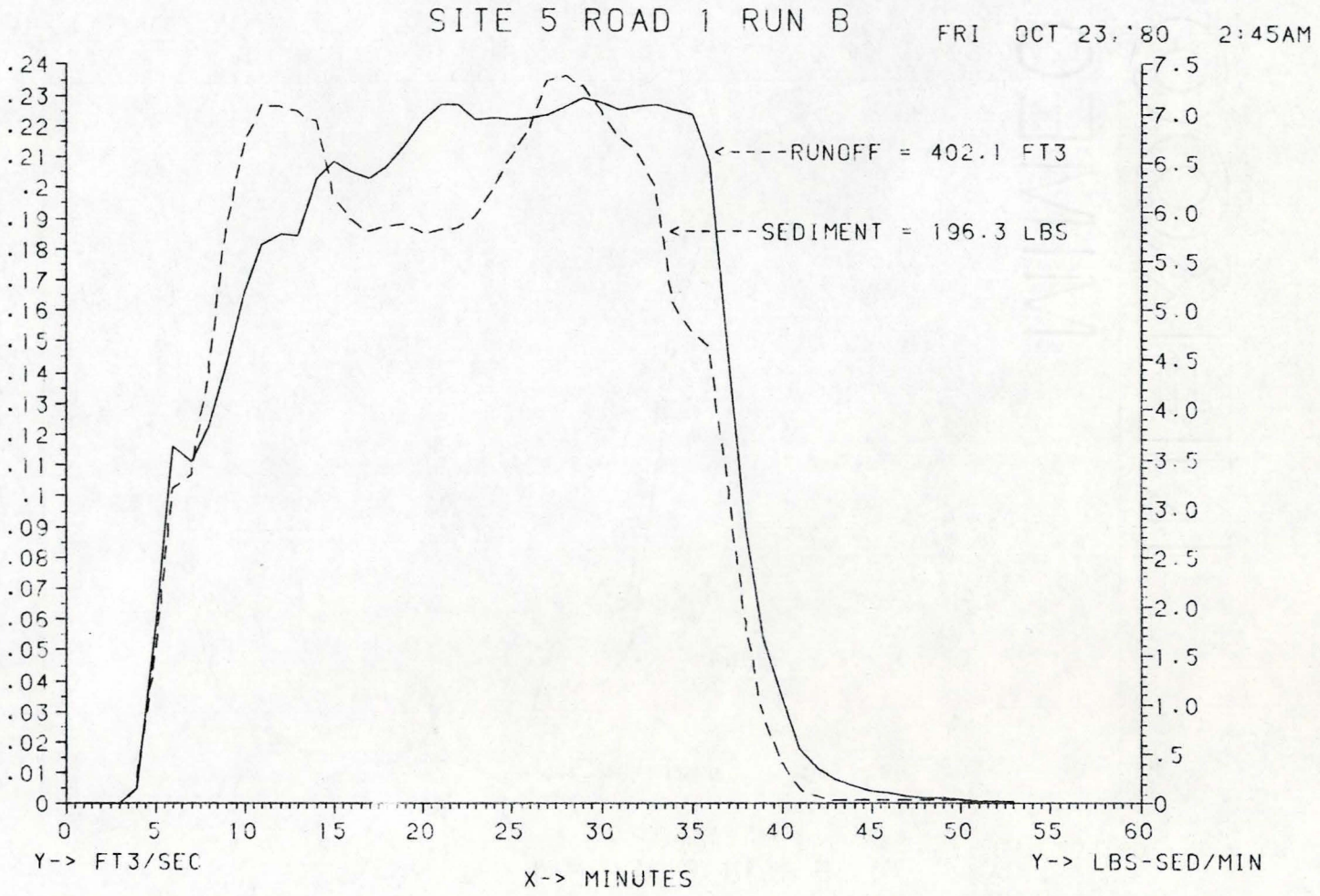

SITE 3 ROAD 2 RUN A
THU OCT 22,'80 9:33PM
.16
.14
.12
.1
.08
.06
.04
.02
0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28 30
<----RUNOFF = 84.34 FT3
<----TOTAL SED = 56.83 LBS
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

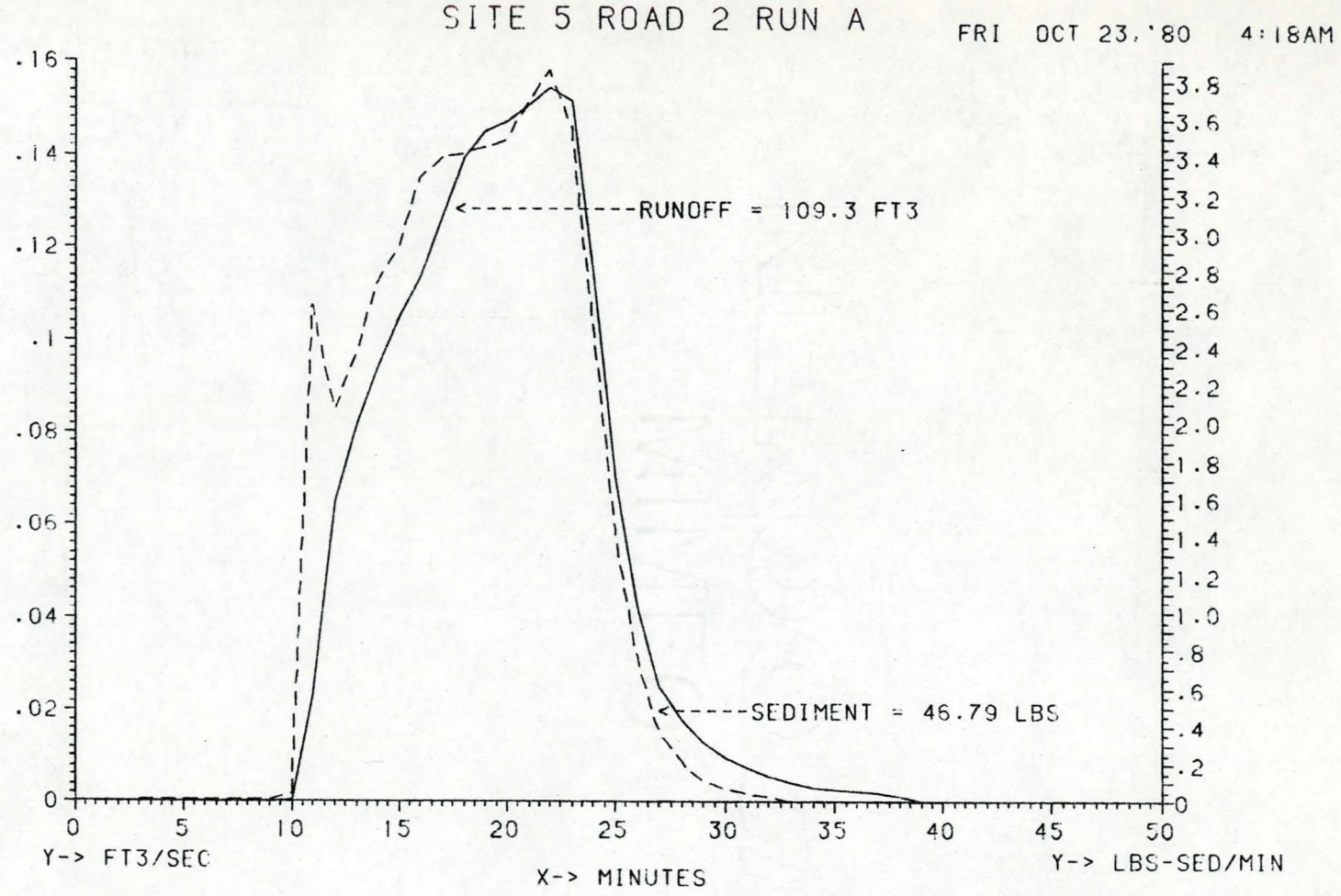

SITE 3 ROAD 2 RUN C
THU OCT 22,'80 10:46PM
<---RUNOFF = 108.8 FT3
<---TOTAL SED = 82.65 LBS
.12
.1
.08
.06
.04
.02
0
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28 30 32
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

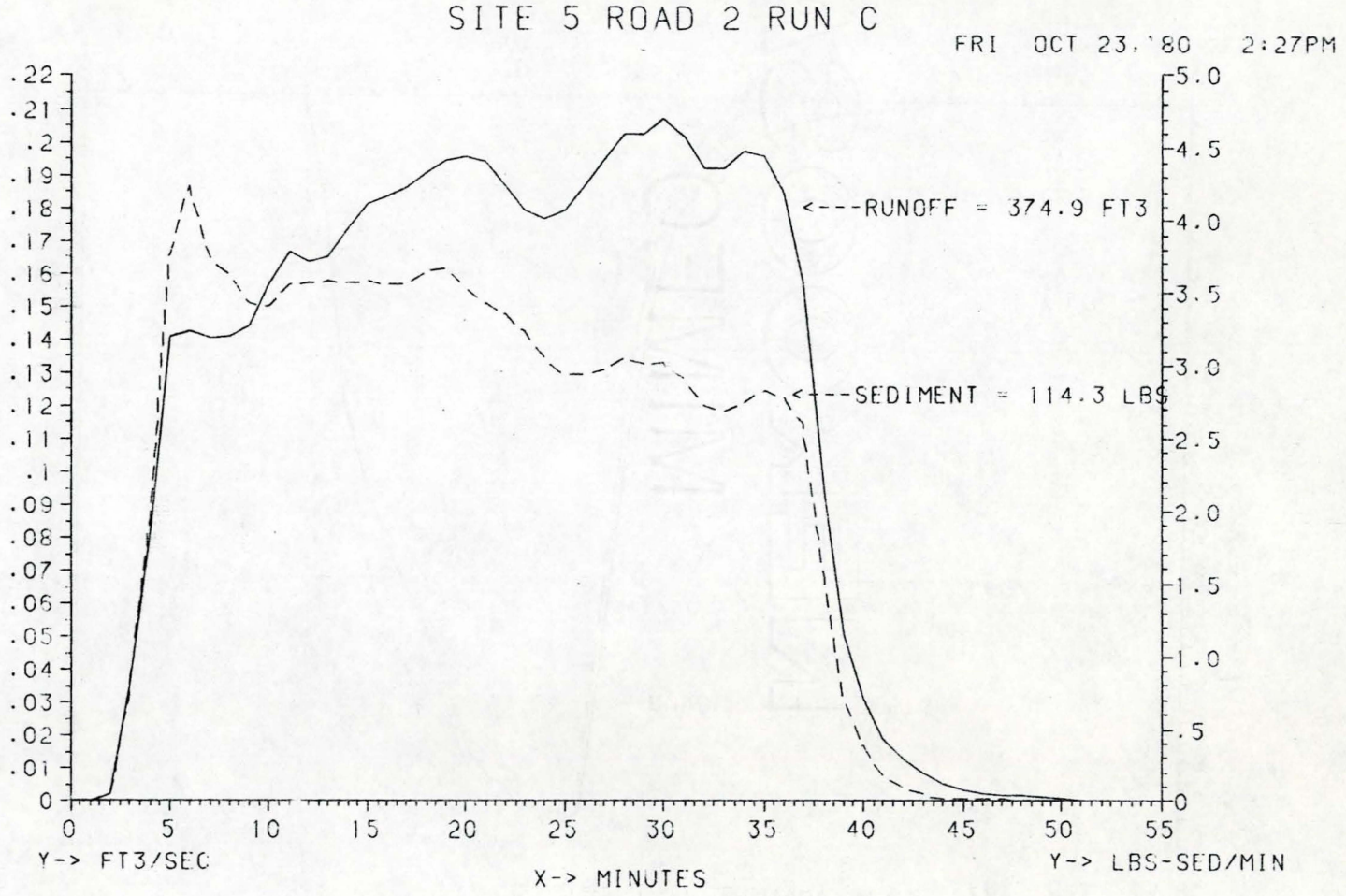

SITE 4 ROAD 1 RUN A
THU OCT 22,'80 11:51PM
<----TOT SEDIMENT = 112.6 LBS
<---RUNOFF = 74.1 FT3
.16
.14
.12
.1
.08
.06
.04
.02
0
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

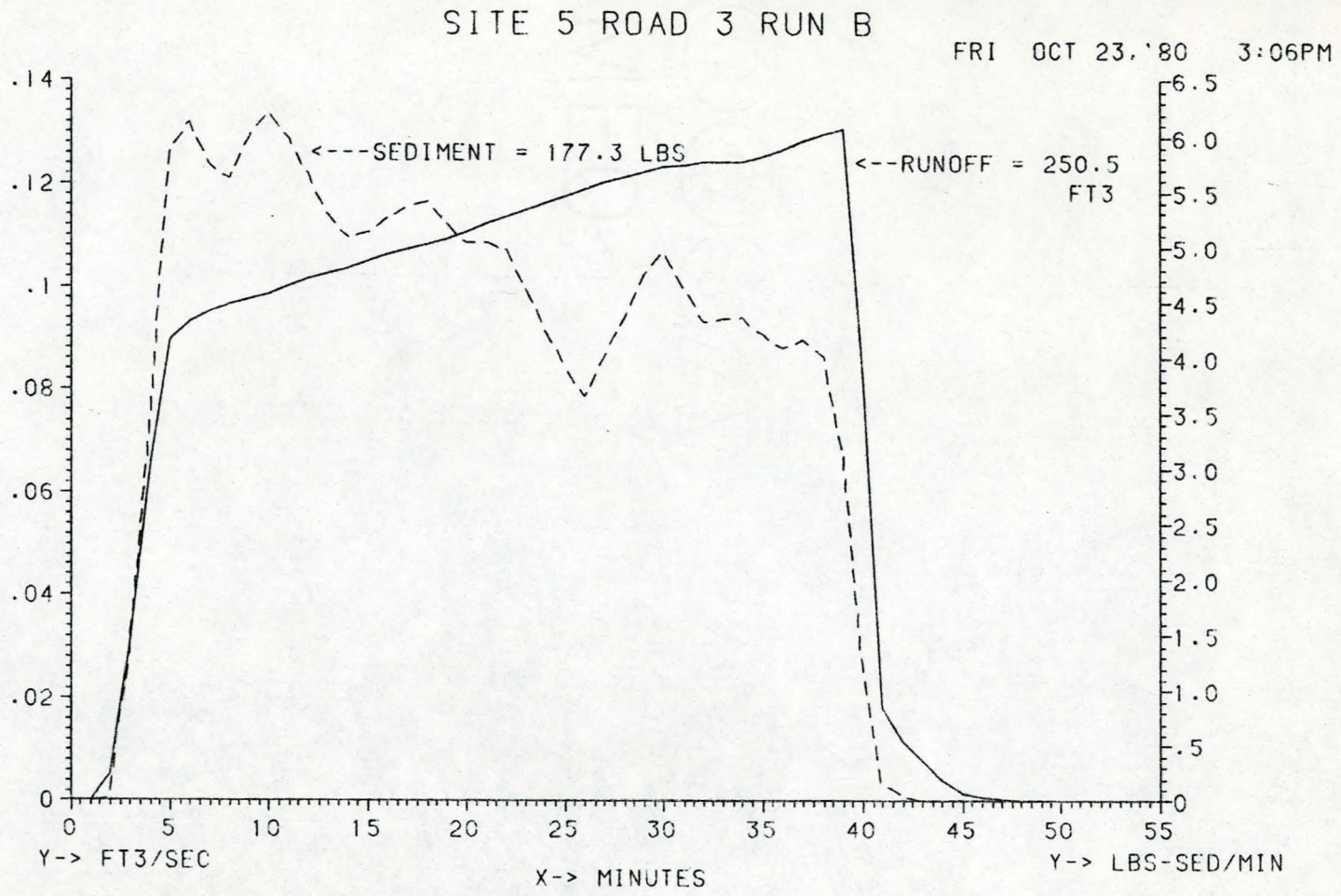

SITE 4 ROAD 2 RUN A
FRI OCT 23, '80 12:52AM
<----RUNOFF = 82.13 FT3
<----SEDIMENT = 80.0 LBS
.18
.16
.14
.12
.1
.08
.06
.04
.02
0
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

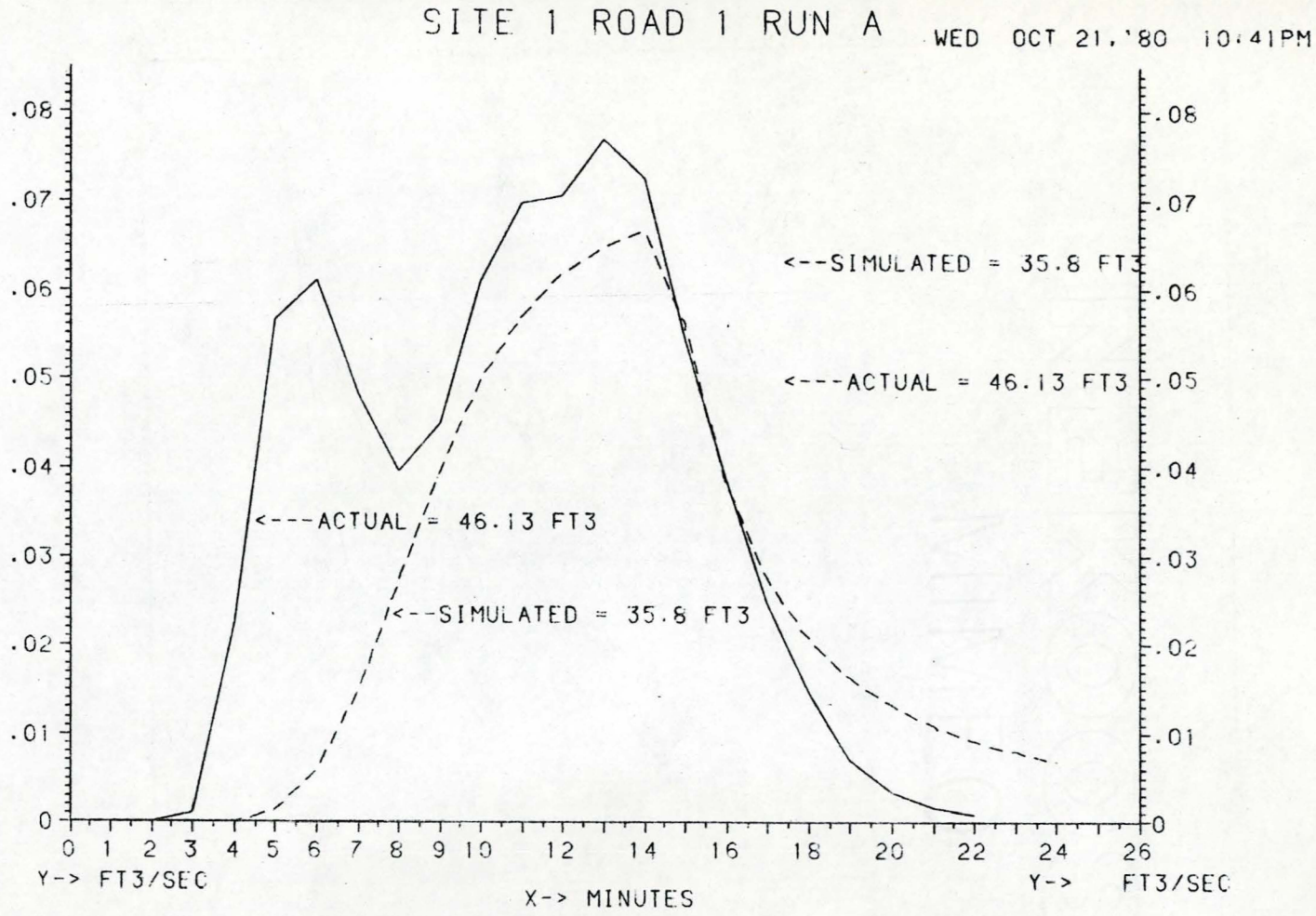

SITE 4 ROAD 2 RUN B
FRI OCT 23, '80 1:43AM
<----SEDIMENT = 204.4 LBS
<---RUNOFF = 227.0 FT3
.22
.21
.2
.19
.18
.17
.16
.15
.14
.13
.12
.11
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
12
10
8
6
4
2
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

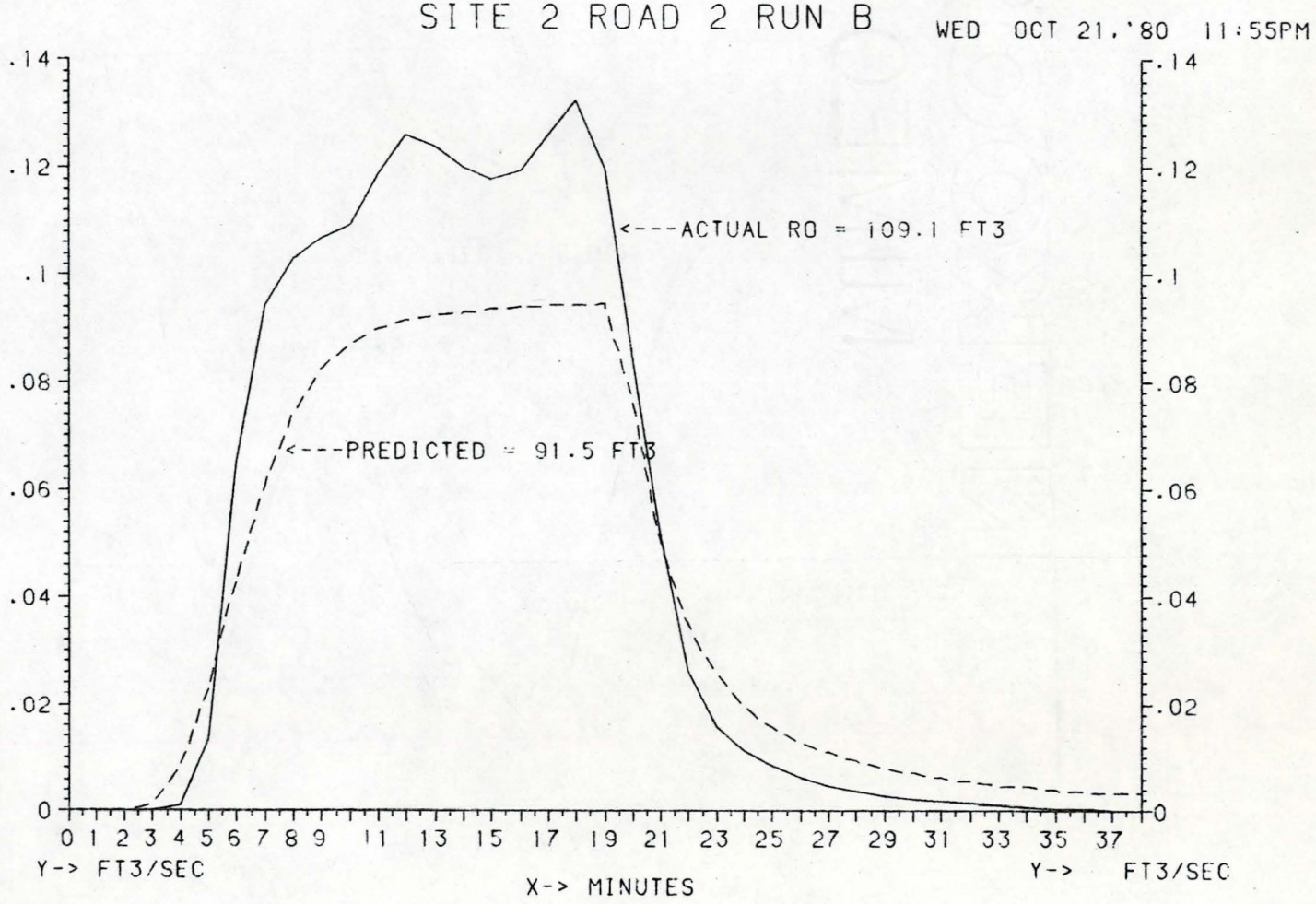

SITE 5 ROAD 1 RUN B
FRI OCT 23, '80 2:45AM
<----RUNOFF = 402.1 FT3
<----SEDIMENT = 196.3 LBS
.24
.23
.22
.21
.2
.19
.18
.17
.16
.15
.14
.13
.12
.11
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0 5 10 15 20 25 30 35 40 45 50 55 60
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

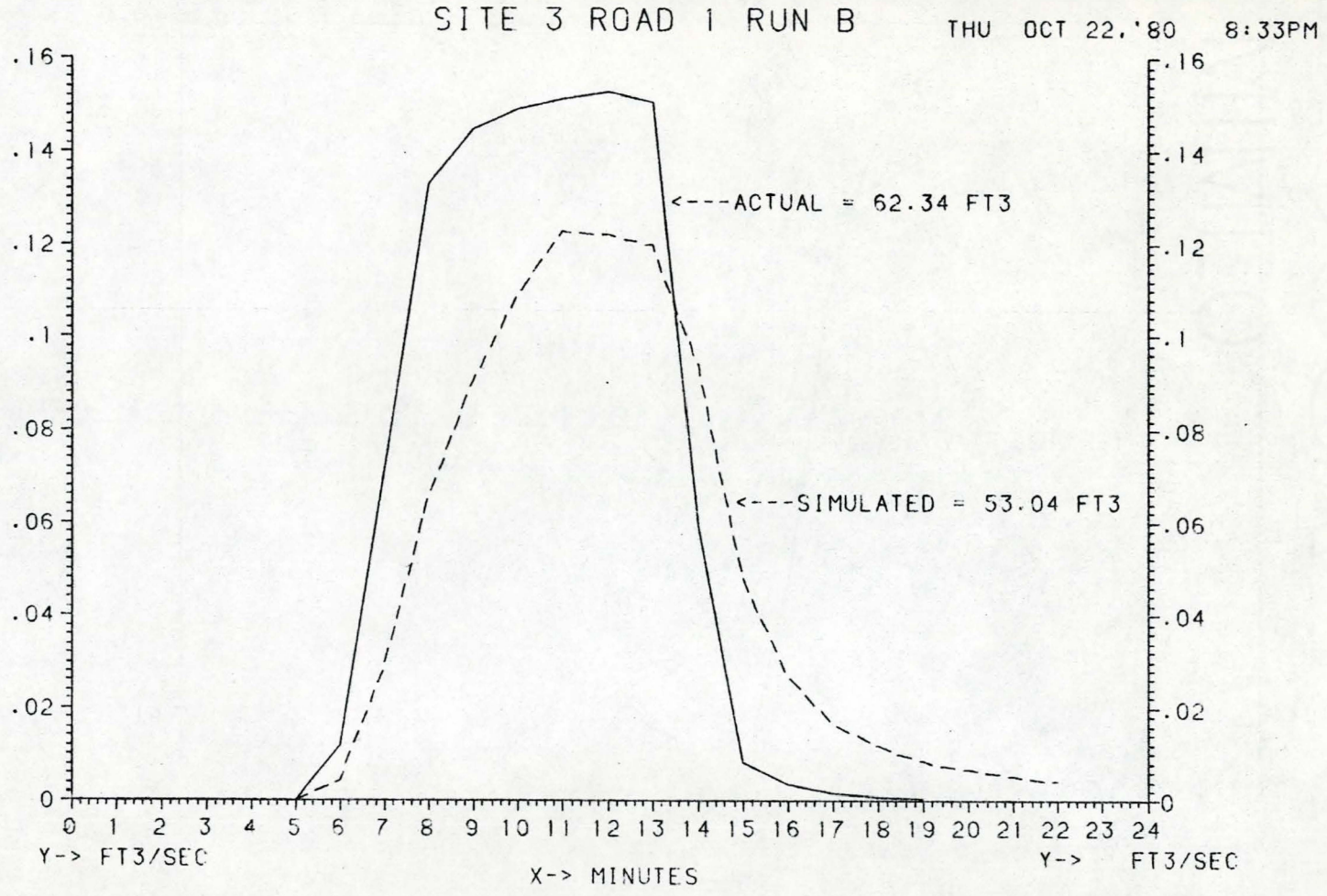

SITE 5 ROAD 2 RUN A
FRI OCT 23, '80 4:18AM
RUNOFF = 109.3 FT3
SEDIMENT = 46.79 LBS
.16
.14
.12
.1
.08
.06
.04
.02
0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
0 5 10 15 20 25 30 35 40 45 50
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

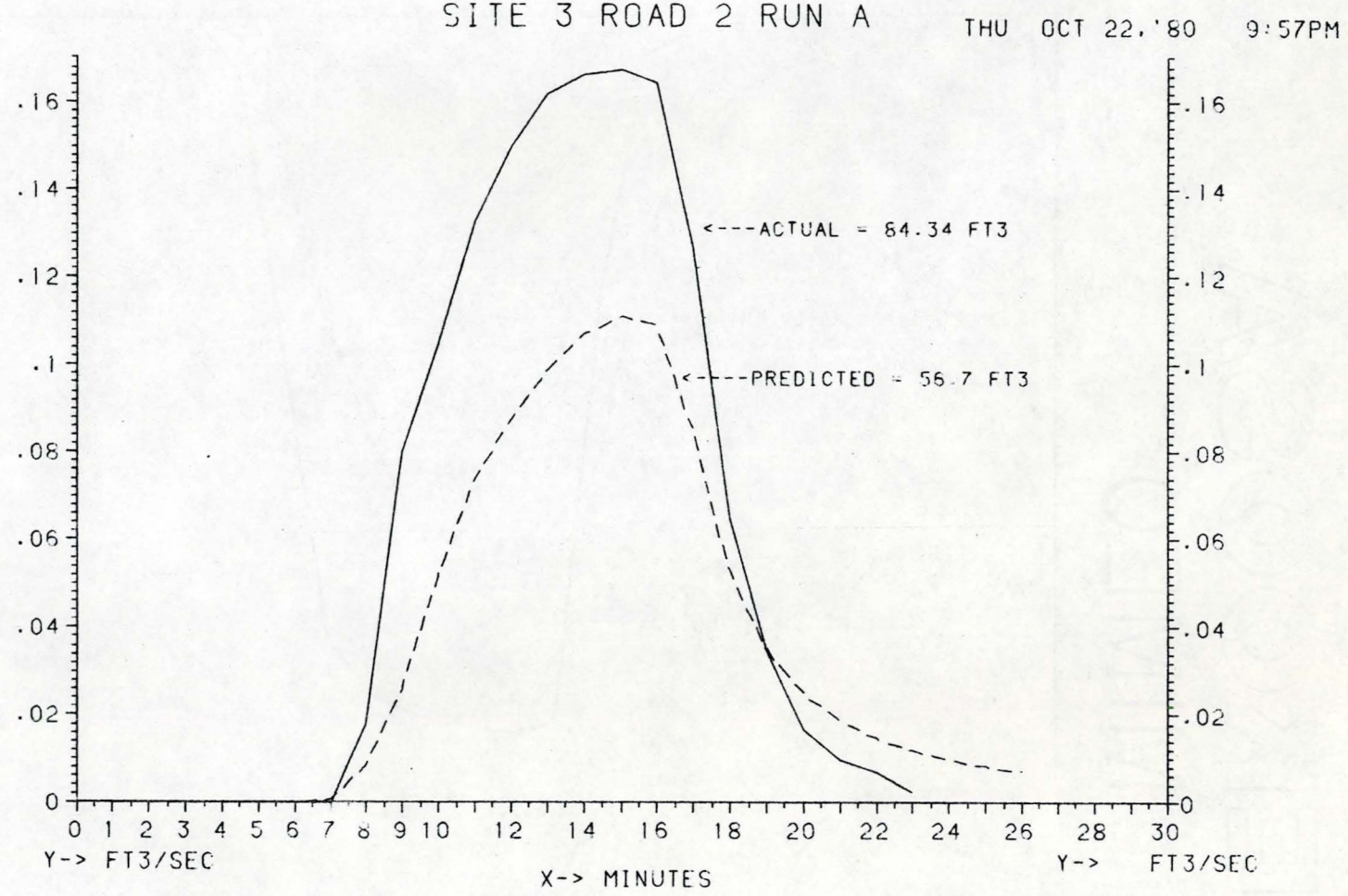

SITE 5 ROAD 2 RUN C
FRI OCT 23, '80 2:27PM
<---RUNOFF = 374.9 FT3
<---SEDIMENT = 114.3 LBS
.22
.21
.2
.19
.18
.17
.16
.15
.14
.13
.12
.11
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0 5 10 15 20 25 30 35 40 45 50 55
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

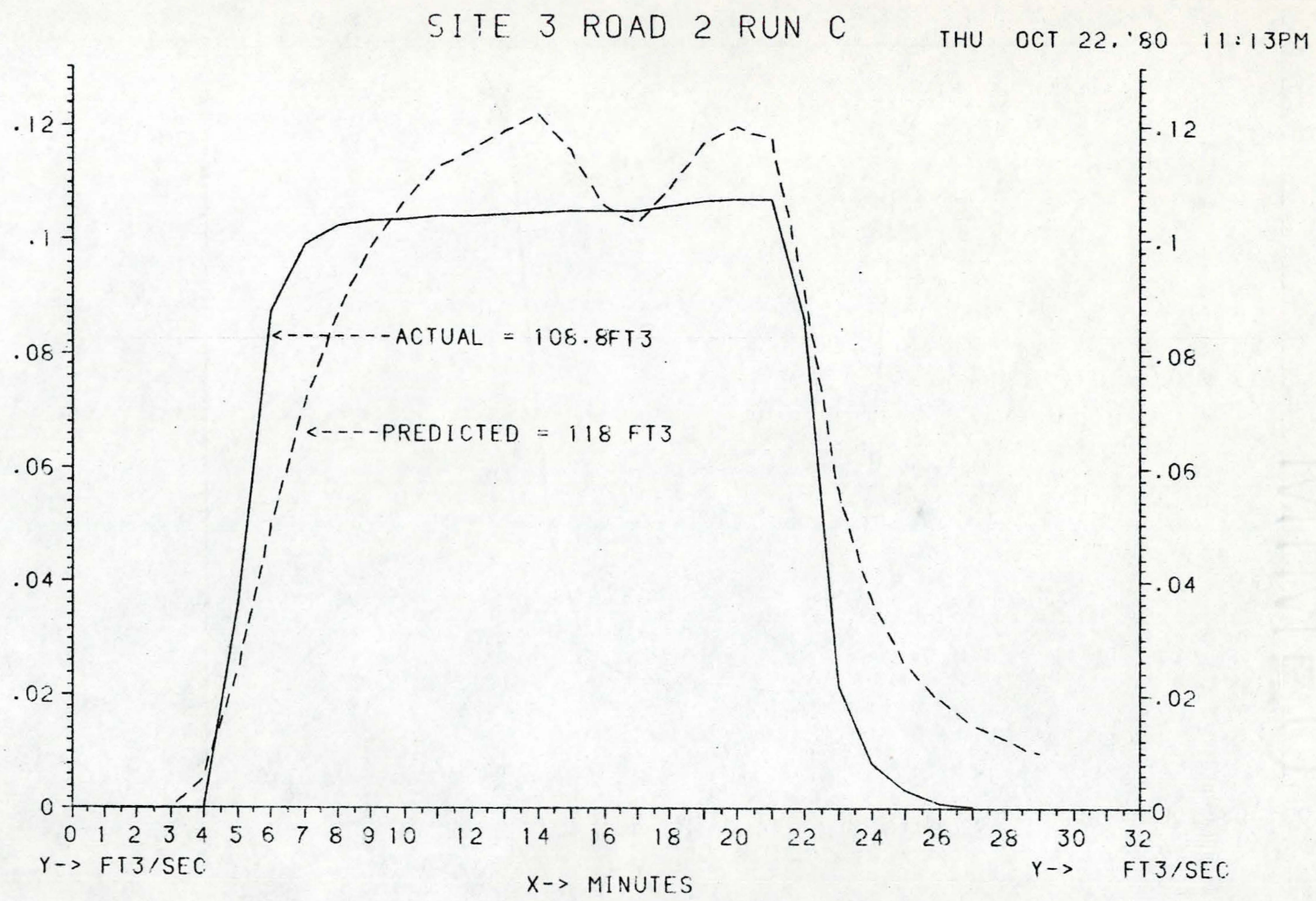

SITE 5 ROAD 3 RUN B
FRI OCT 23,'80 3:06PM
<---SEDIMENT = 177.3 LBS
<--RUNOFF = 250.5 FT3
.14
.12
.1
.08
.06
.04
.02
0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0 5 10 15 20 25 30 35 40 45 50 55
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

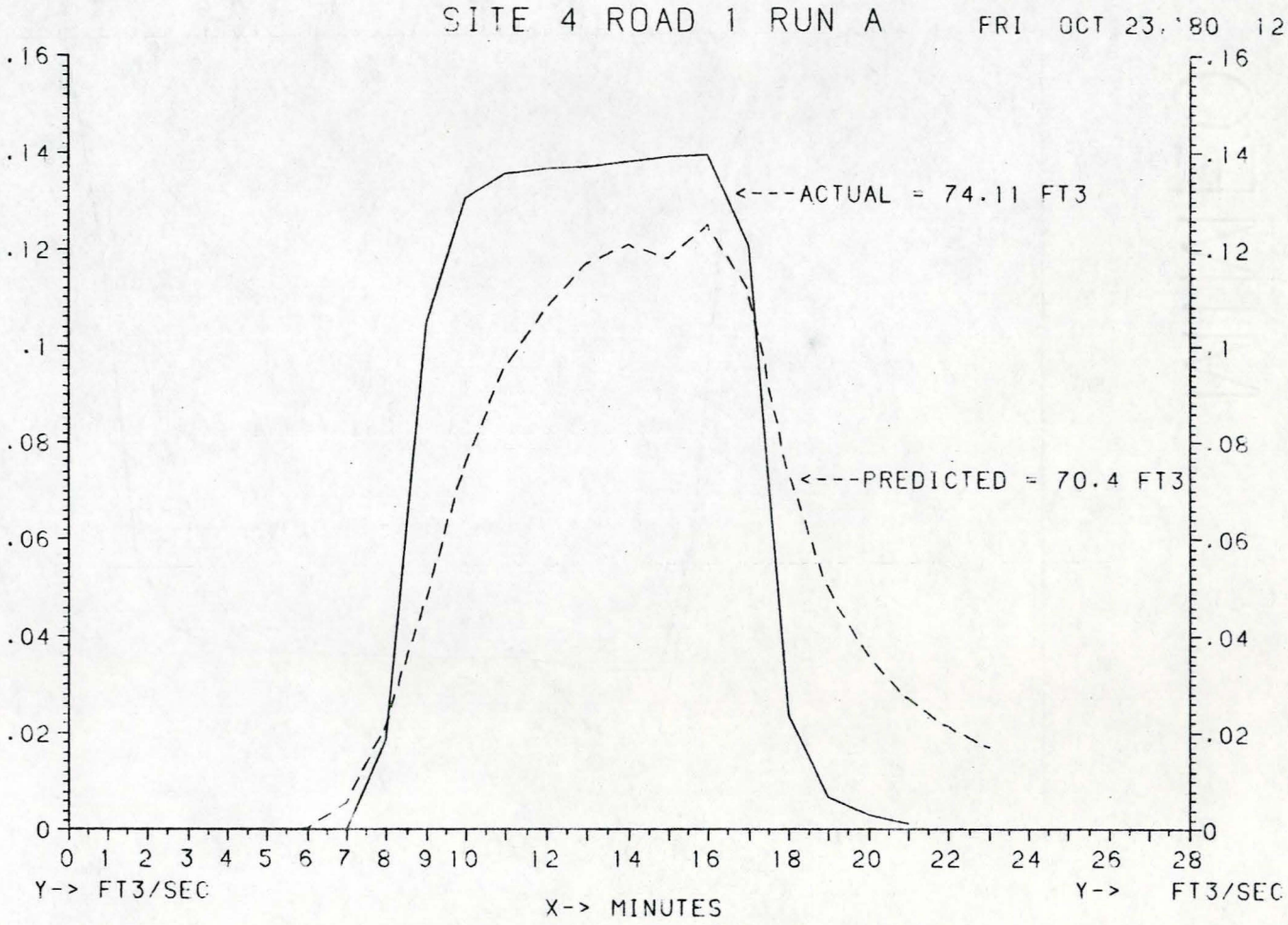

SITE 1 ROAD 1 RUN A
WED OCT 21,'80 10:41PM
.08
.07
.06
.05
.04
.03
.02
.01
0
<---ACTUAL = 46.13 FT3
<--SIMULATED = 35.8 FT3
<--SIMULATED = 35.8 FT3
<---ACTUAL = 46.13 FT3
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

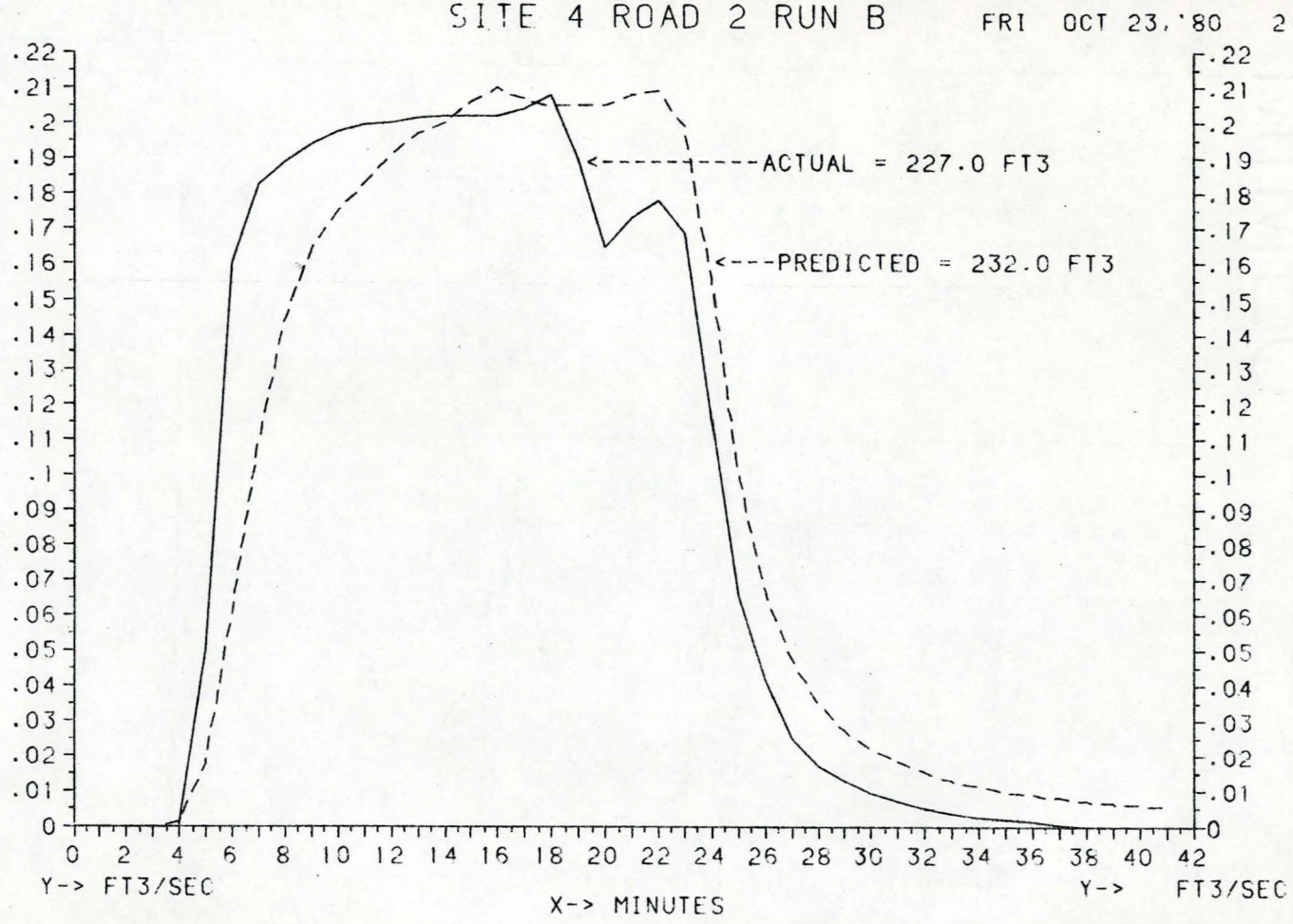

SITE 2 ROAD 2 RUN B
WED OCT 21,'80 11:55PM
<---ACTUAL RO = 109.1 FT3
<---PREDICTED = 91.5 FT3
.14
.12
.1
.08
.06
.04
.02
0
0 1 2 3 4 5 6 7 8 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

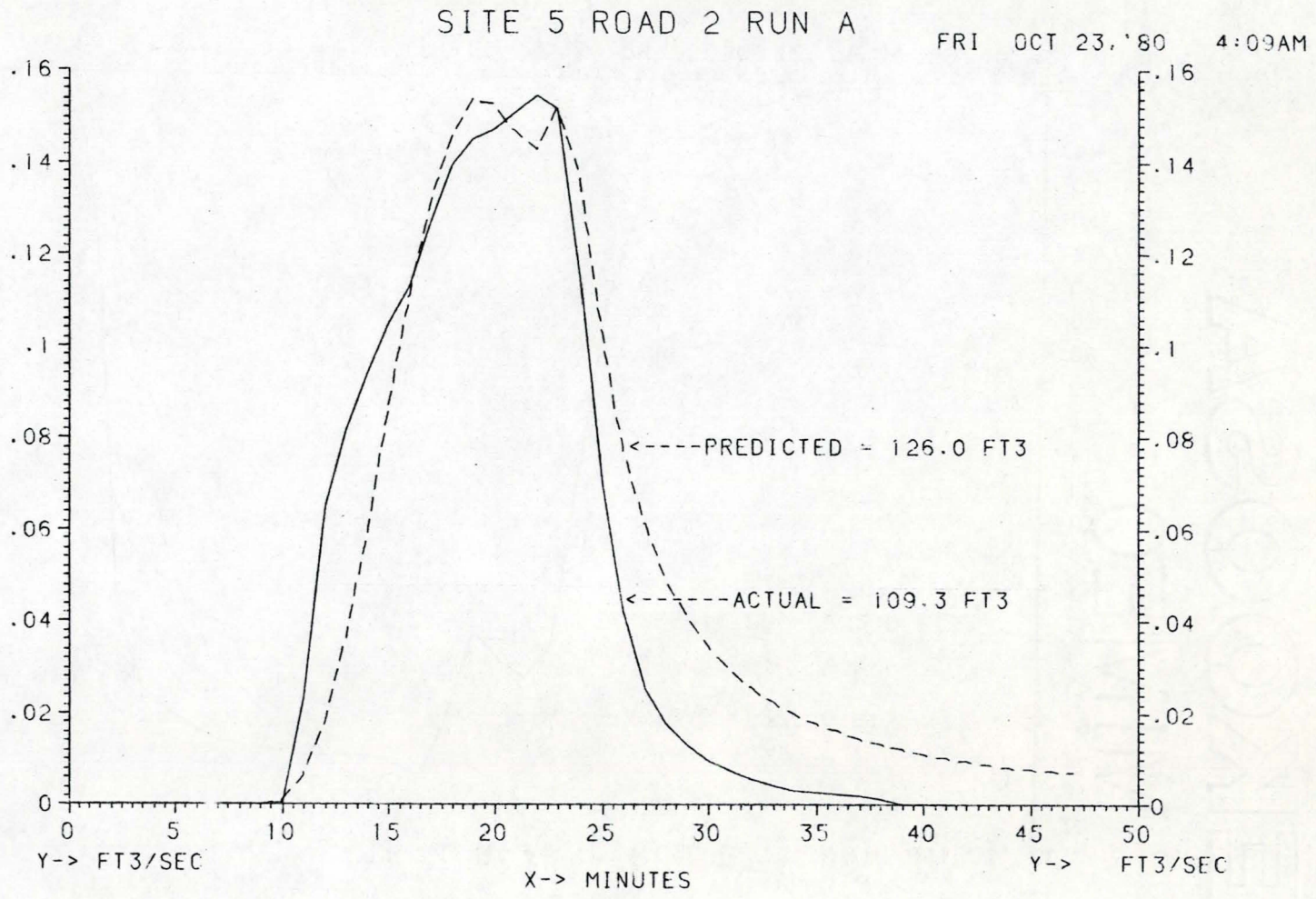

SITE 3 ROAD 1 RUN B
THU OCT 22,'80 8:33PM
<---ACTUAL = 62.34 FT3
<---SIMULATED = 53.04 FT3
.16
.14
.12
.1
.08
.06
.04
.02
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

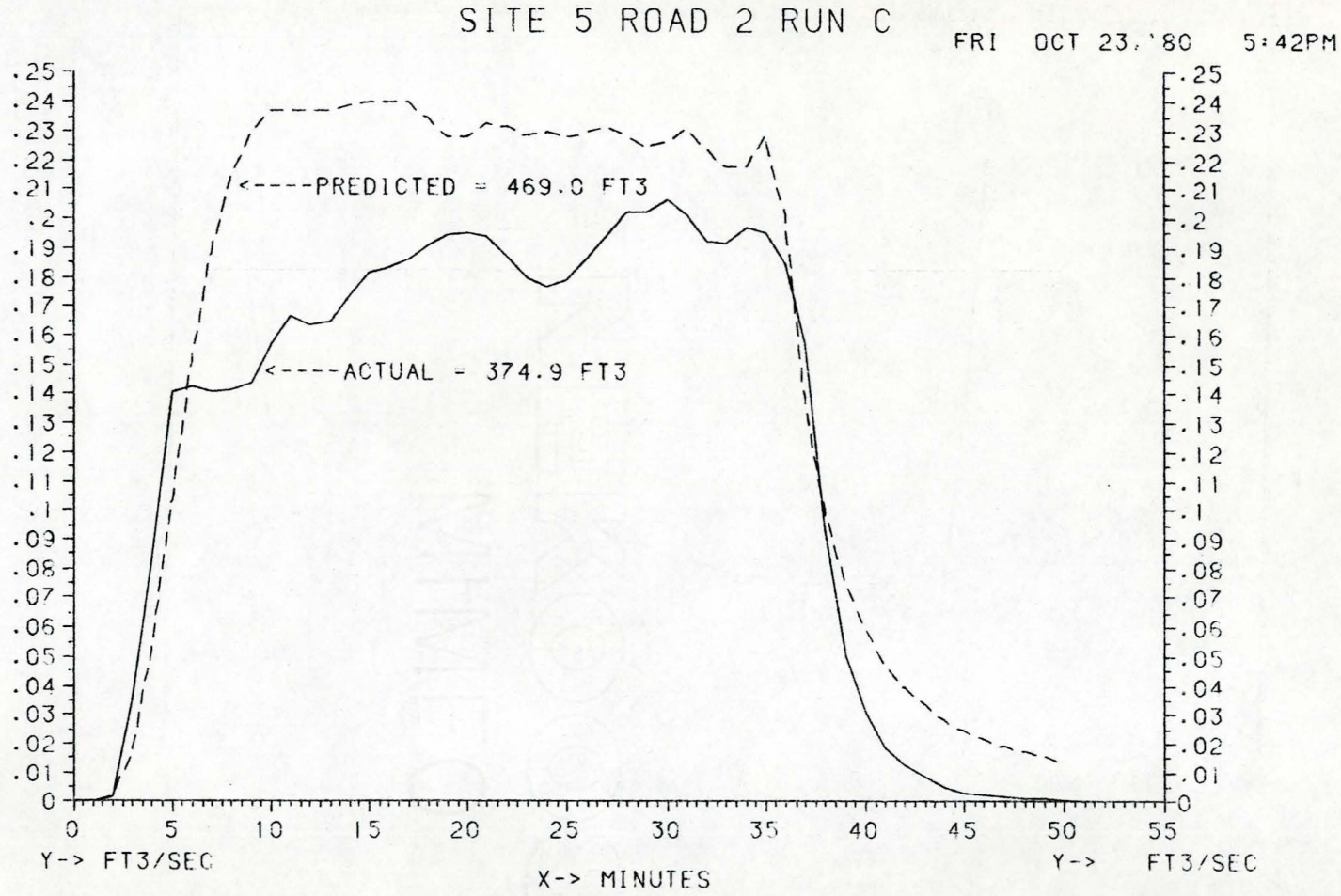

SITE 3 ROAD 2 RUN A
THU OCT 22,'80 9:57PM
<---ACTUAL = 84.34 FT3
<---PREDICTED = 56.7 FT3
.16
.14
.12
.1
.08
.06
.04
.02
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28 30
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

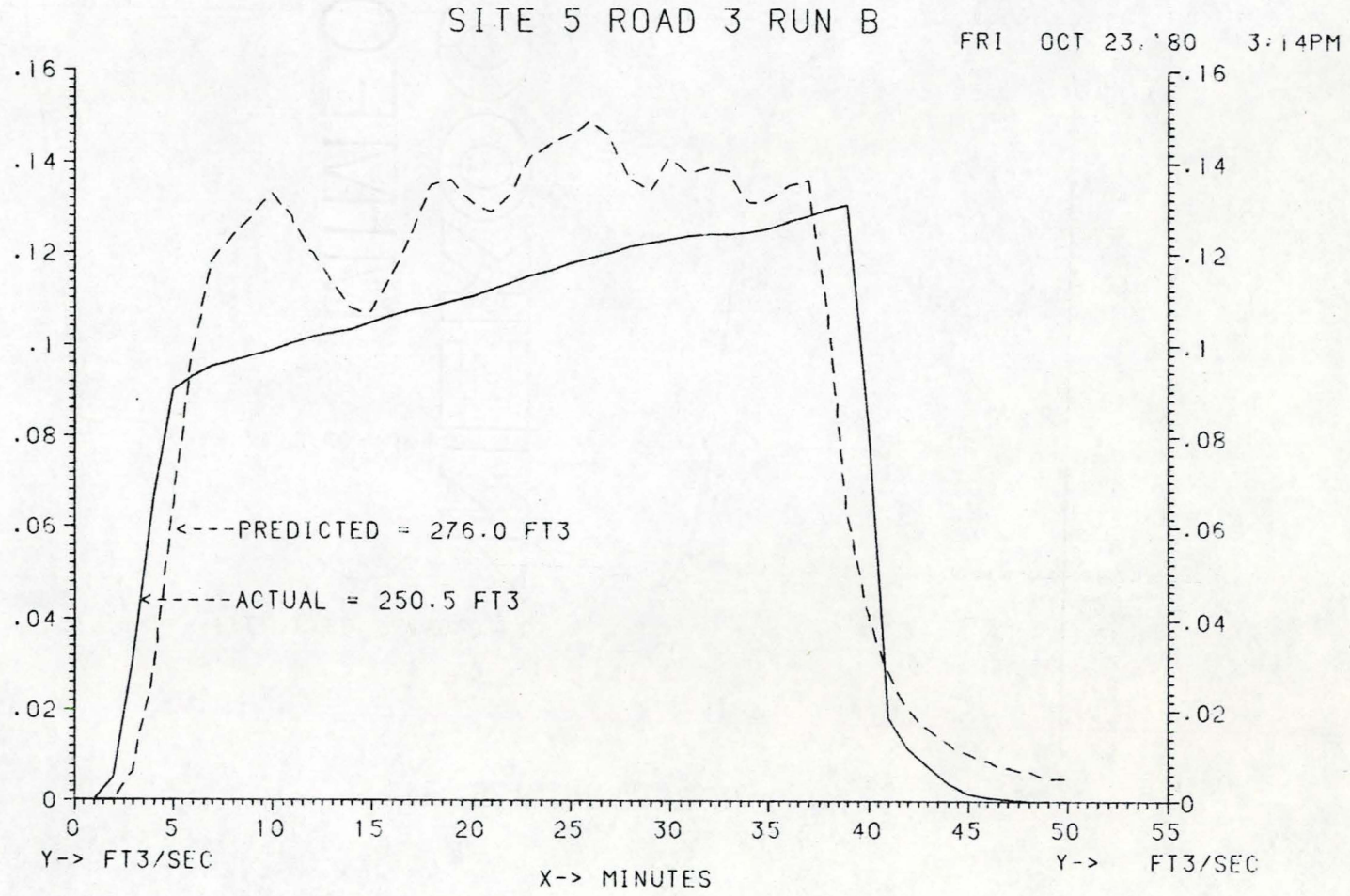

SITE 3 ROAD 2 RUN C
THU OCT 22,'80 11:13PM
.12
.1
.08
.06
.04
.02
0
<----ACTUAL = 108.8FT3
<----PREDICTED = 118 FT3
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28 30 32
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

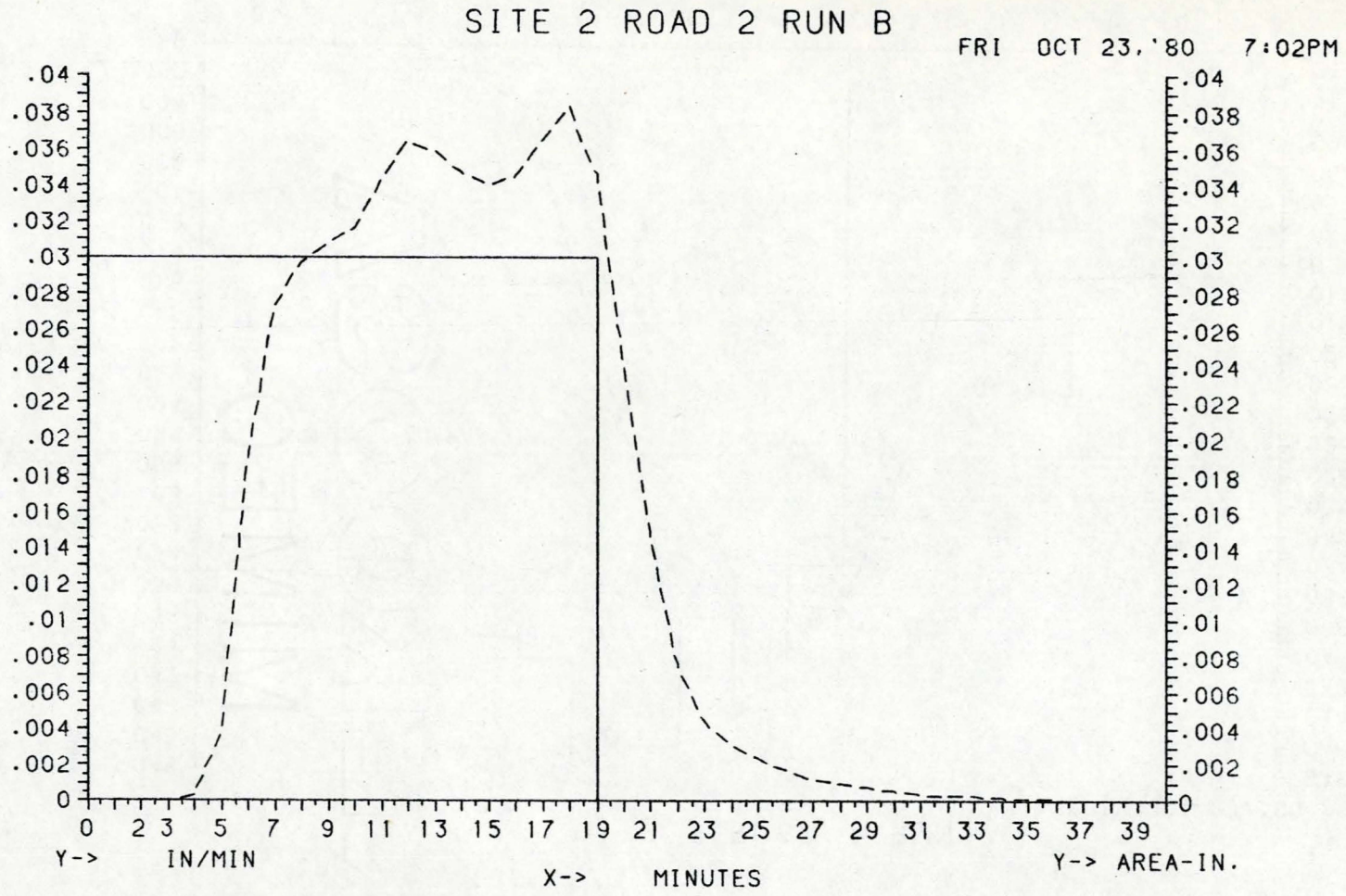

SITE 4 ROAD 1 RUN A
FRI OCT 23, '80 12:15AM
<---ACTUAL = 74.11 FT3
<---PREDICTED = 70.4 FT3
.16
.14
.12
.1
.08
.06
.04
.02
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

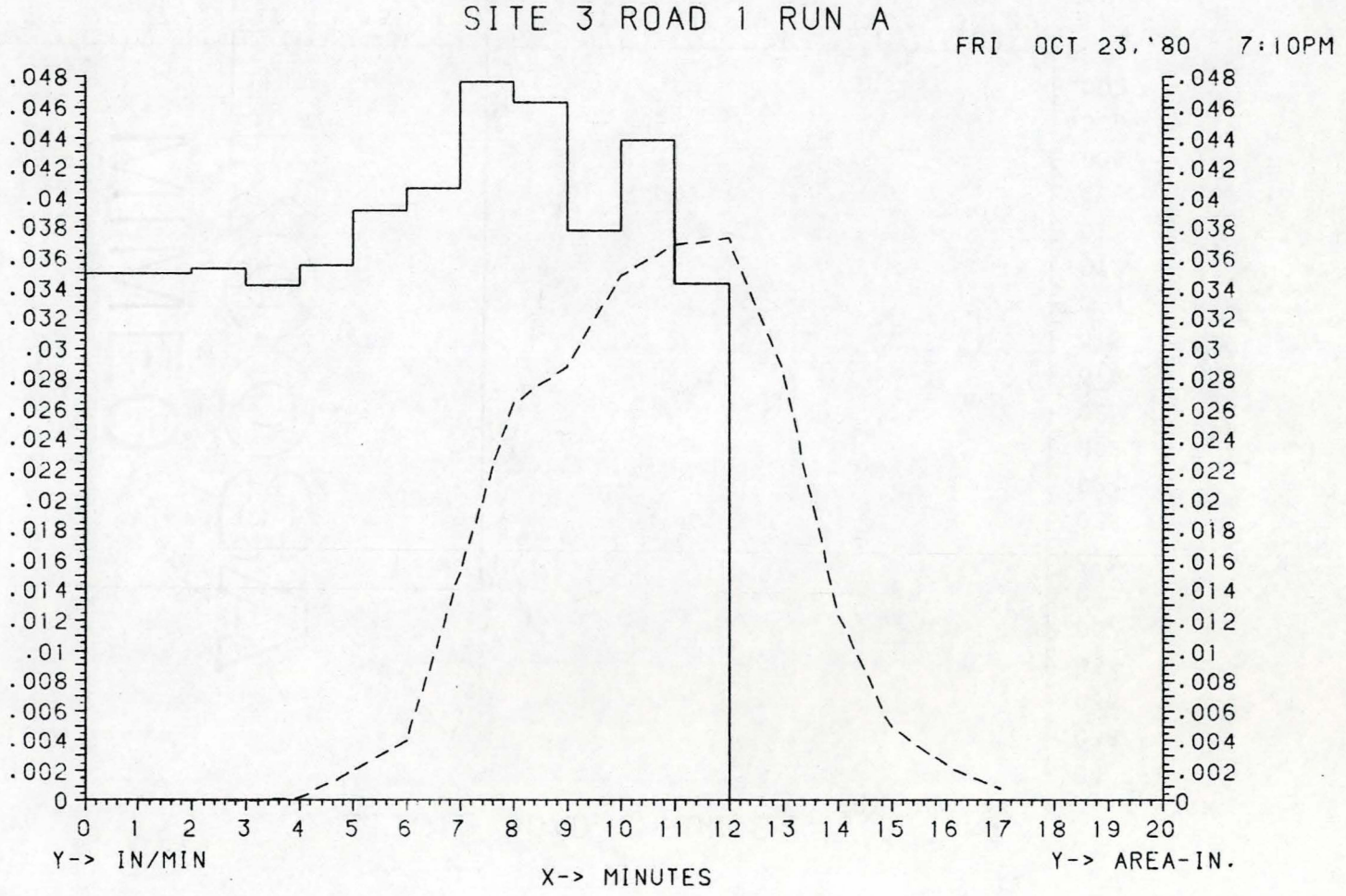

SITE 4 ROAD 2 RUN B
FRI OCT 23, '80 2:10AM
<----------ACTUAL = 227.0 FT3
<---PREDICTED = 232.0 FT3
.22
.21
.2
.19
.18
.17
.16
.15
.14
.13
.12
.11
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

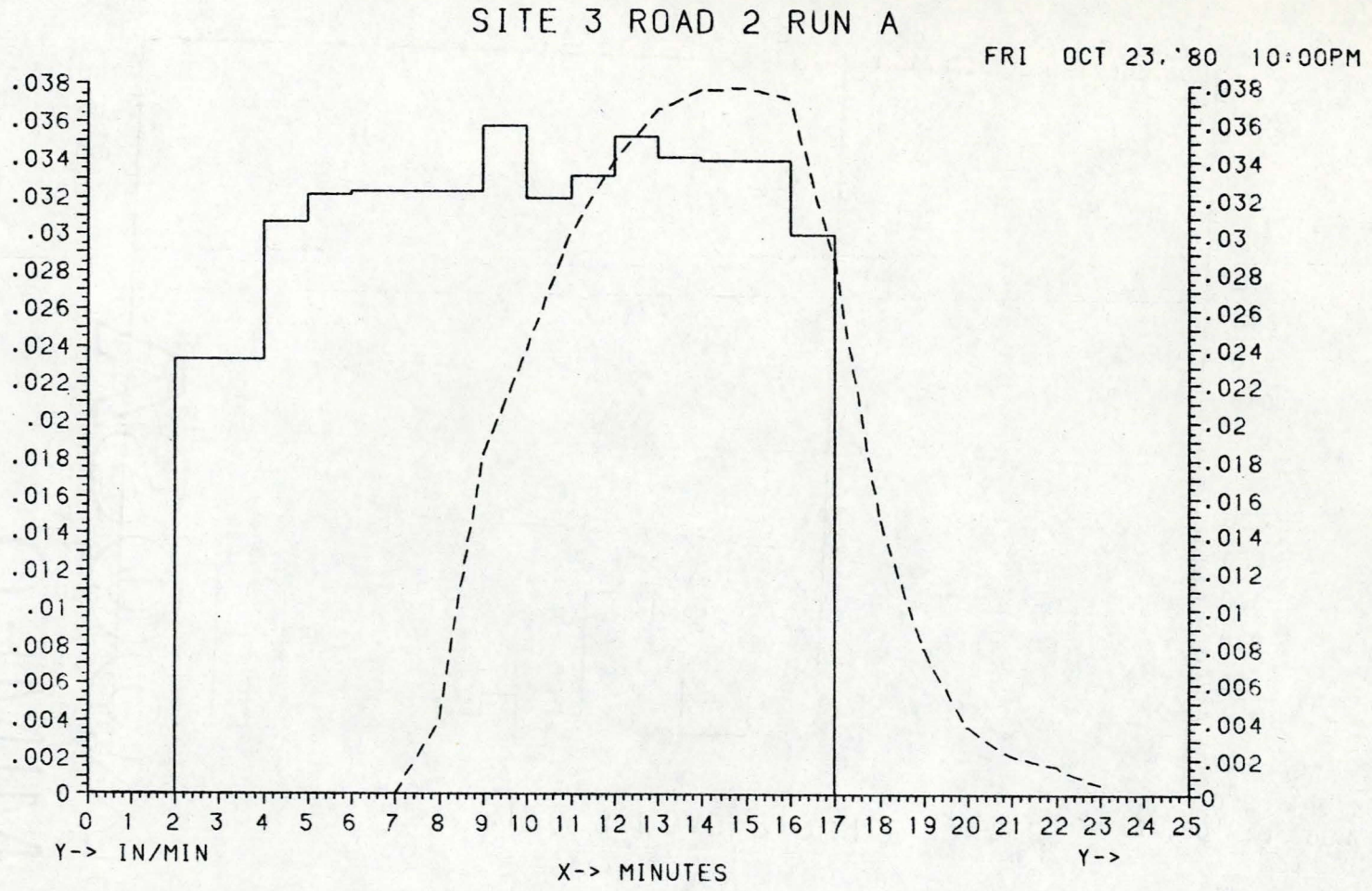

SITE 5 ROAD 2 RUN A
FRI OCT 23,'80 4:09AM
.16
.14
.12
.1
.08
.06
.04
.02
0
<----PREDICTED = 126.0 FT3
<----ACTUAL = 109.3 FT3
0 5 10 15 20 25 30 35 40 45 50
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

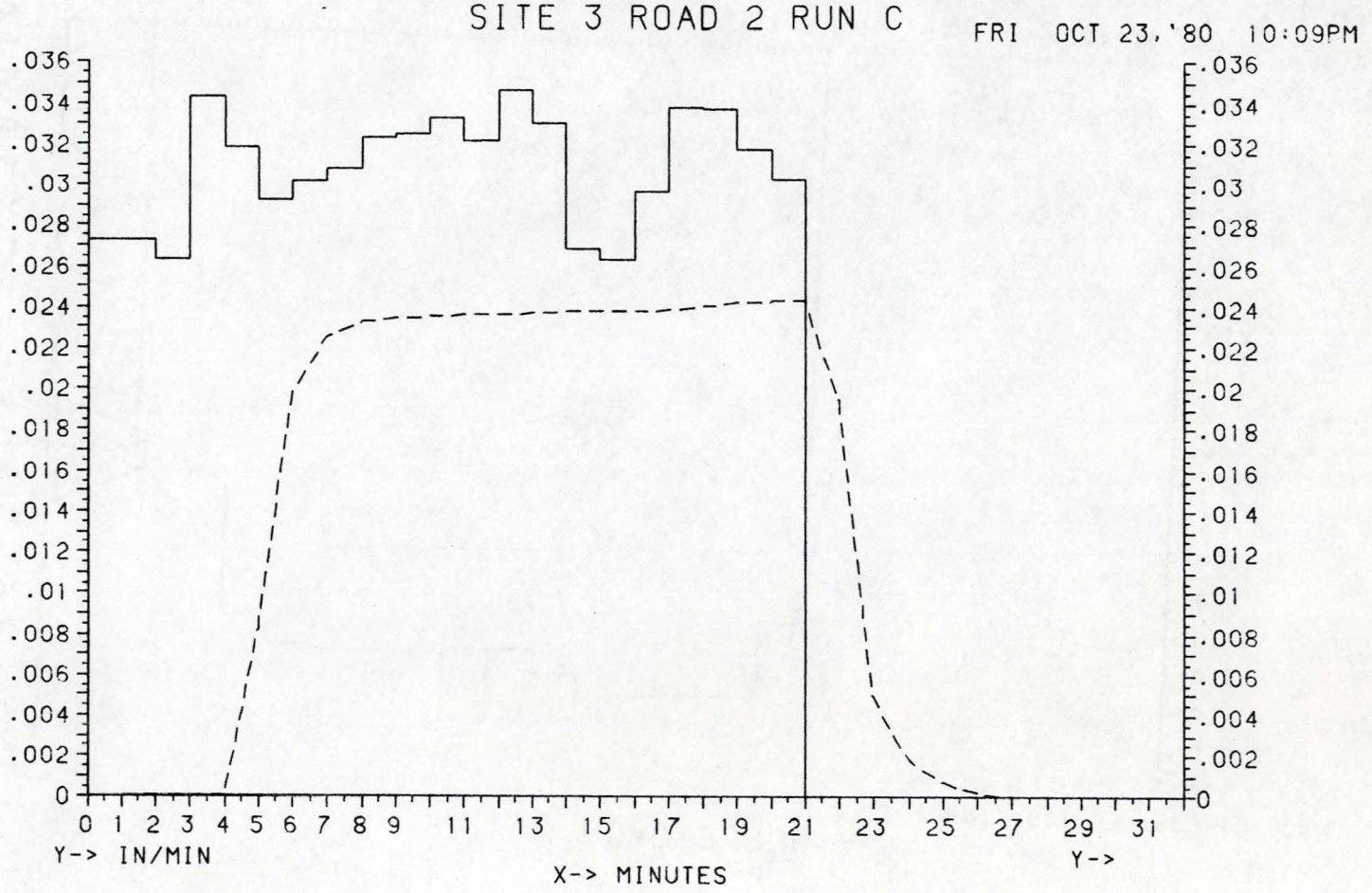

SITE 5 ROAD 2 RUN C
FRI OCT 23,'80 5:42PM
<----PREDICTED = 469.0 FT3
<----ACTUAL = 374.9 FT3
.25
.24
.23
.22
.21
.2
.19
.18
.17
.16
.15
.14
.13
.12
.11
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
0 5 10 15 20 25 30 35 40 45 50 55
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

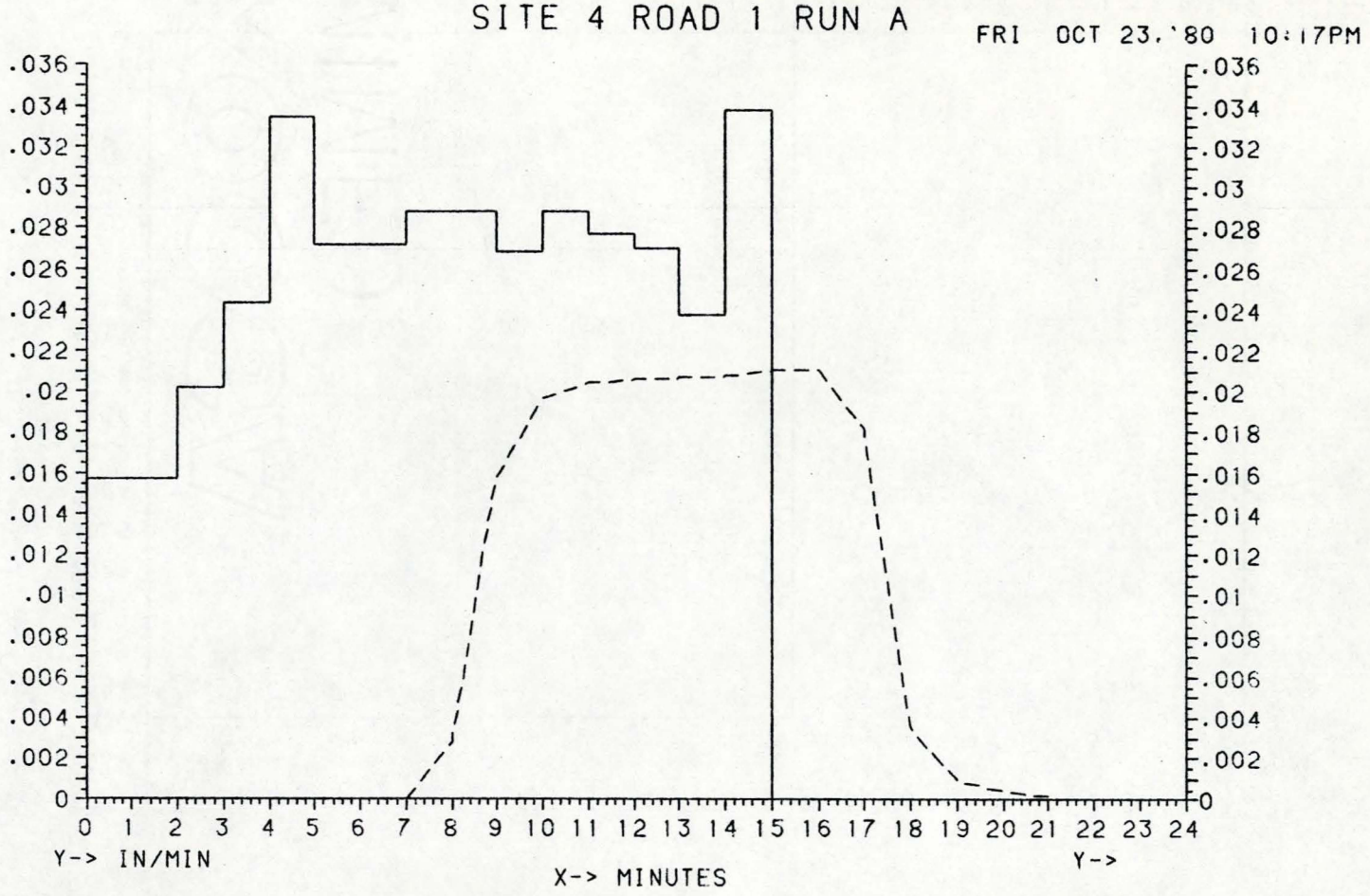

SITE 5 ROAD 3 RUN B
FRI OCT 23, '80 3:14PM
.16
.14
.12
.1
.08
.06
.04
.02
0
<---PREDICTED = 276.0 FT3
<----ACTUAL = 250.5 FT3
0 5 10 15 20 25 30 35 40 45 50 55
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

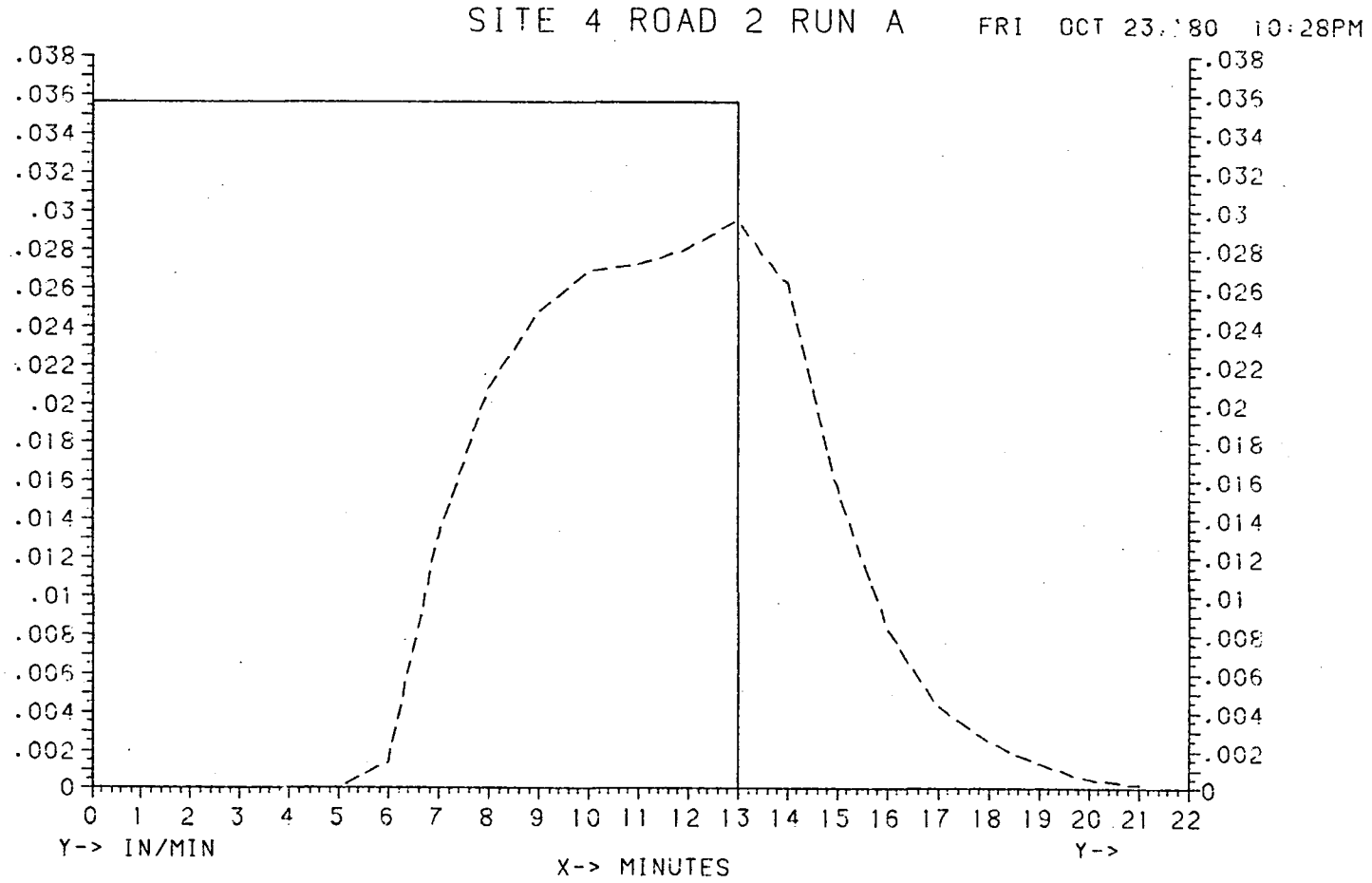

SITE 2 ROAD 2 RUN B
FRI OCT 23,'80 7:02PM
.04
.038
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 2 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39
Y-> IN/MIN
X-> MINUTES
Y-> AREA-IN.

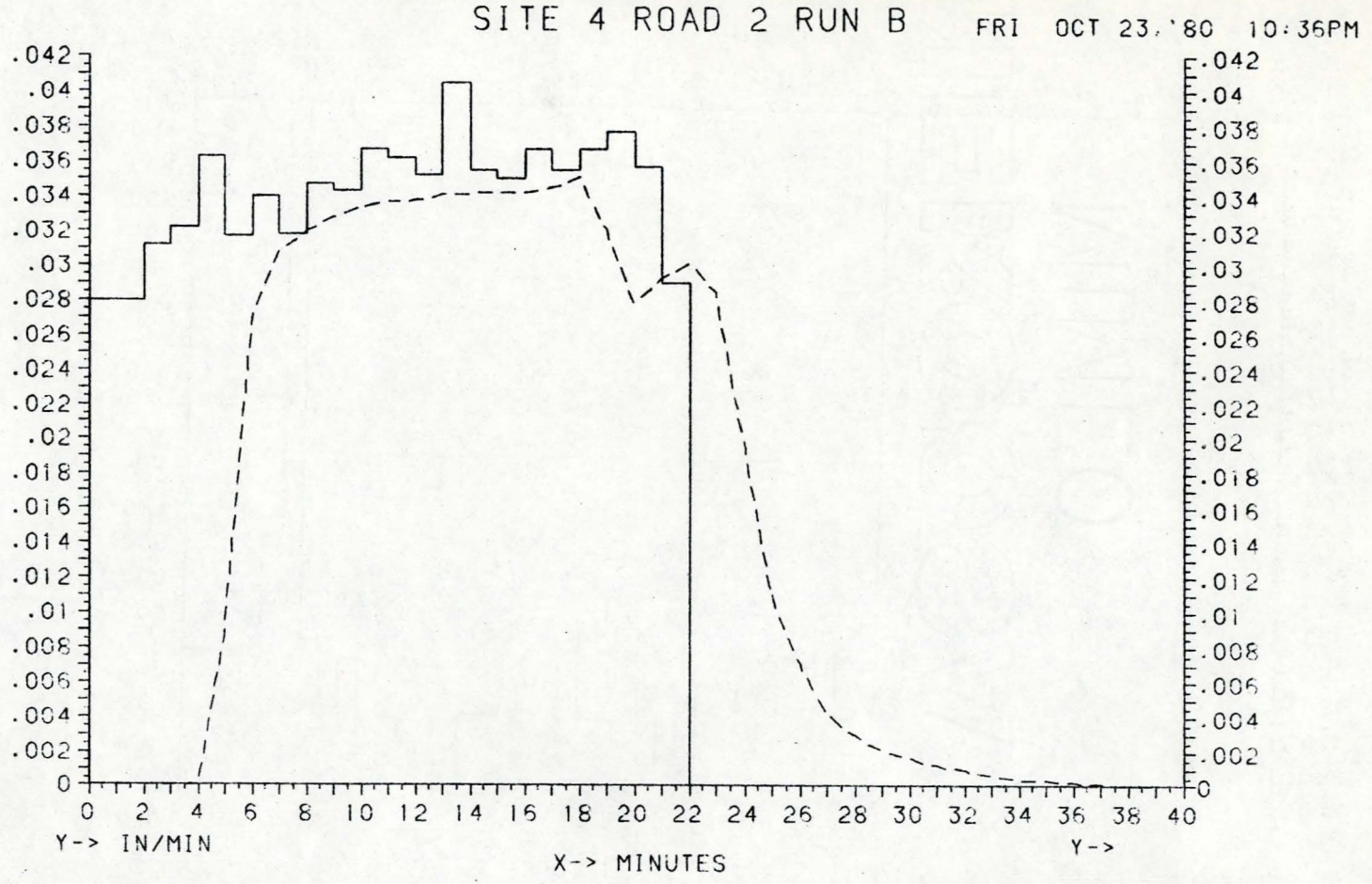

SITE 3 ROAD 1 RUN A
FRI OCT 23,'80 7:10PM
.048
.046
.044
.042
.04
.038
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Y-> IN/MIN
X-> MINUTES
Y-> AREA-IN.

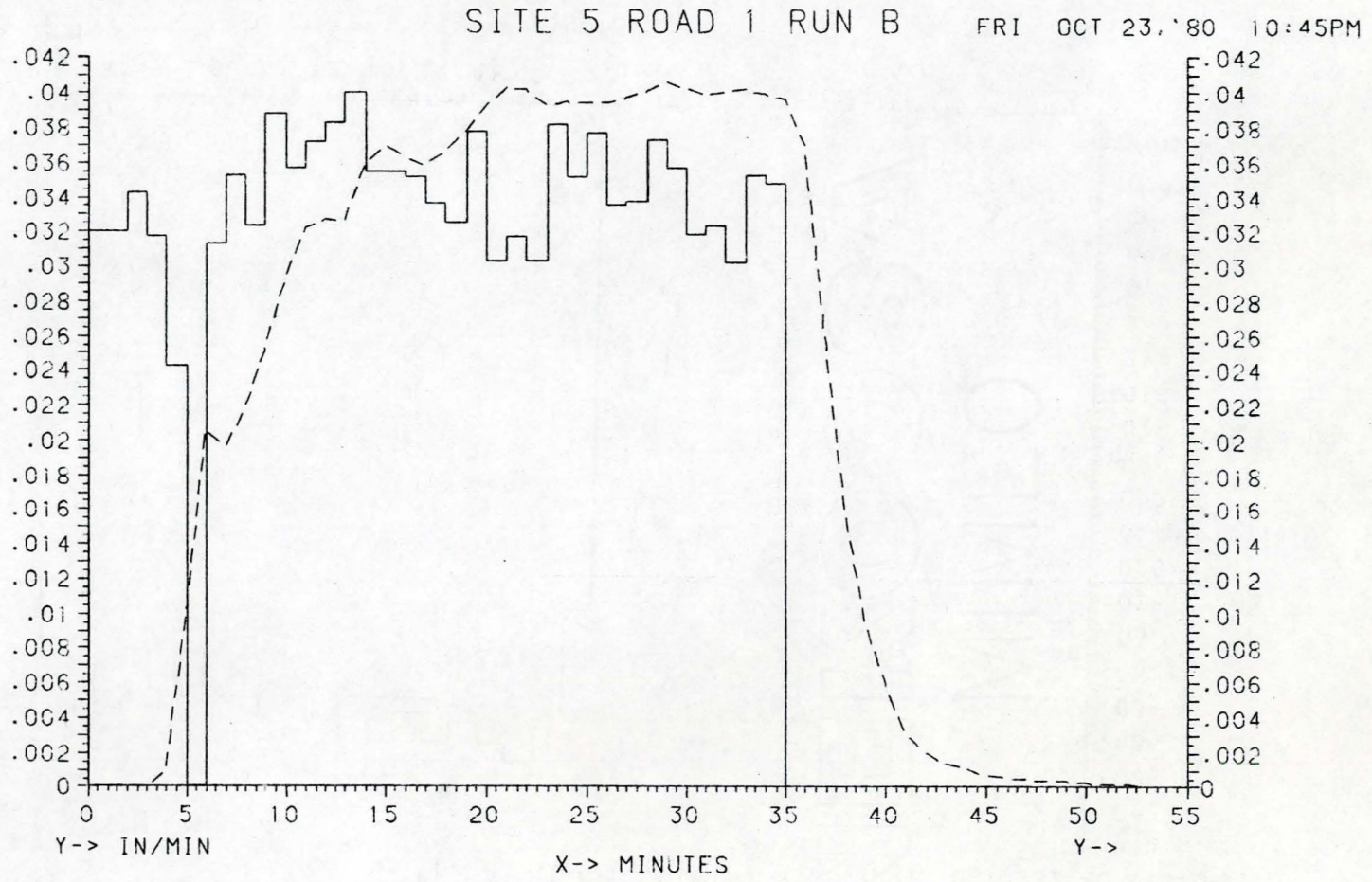

SITE 3 ROAD 2 RUN A
FRI OCT 23,'80 10:00PM
.038
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Y-> IN/MIN
X-> MINUTES
Y->

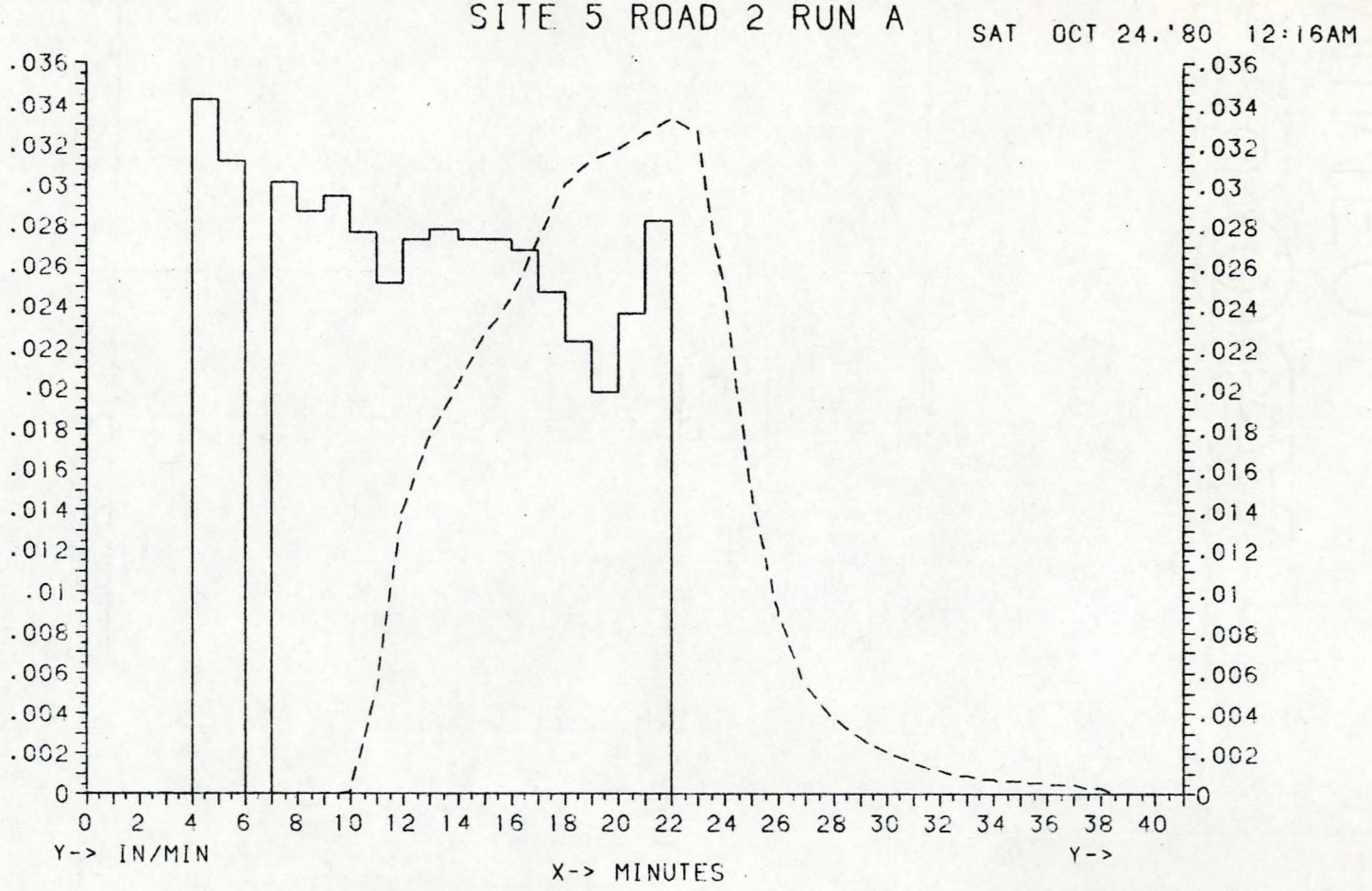

SITE 3 ROAD 2 RUN C
FRI OCT 23,'80 10:09PM
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 1 2 3 4 5 6 7 8 9 11 13 15 17 19 21 23 25 27 29 31
Y-> IN/MIN
X-> MINUTES
Y->

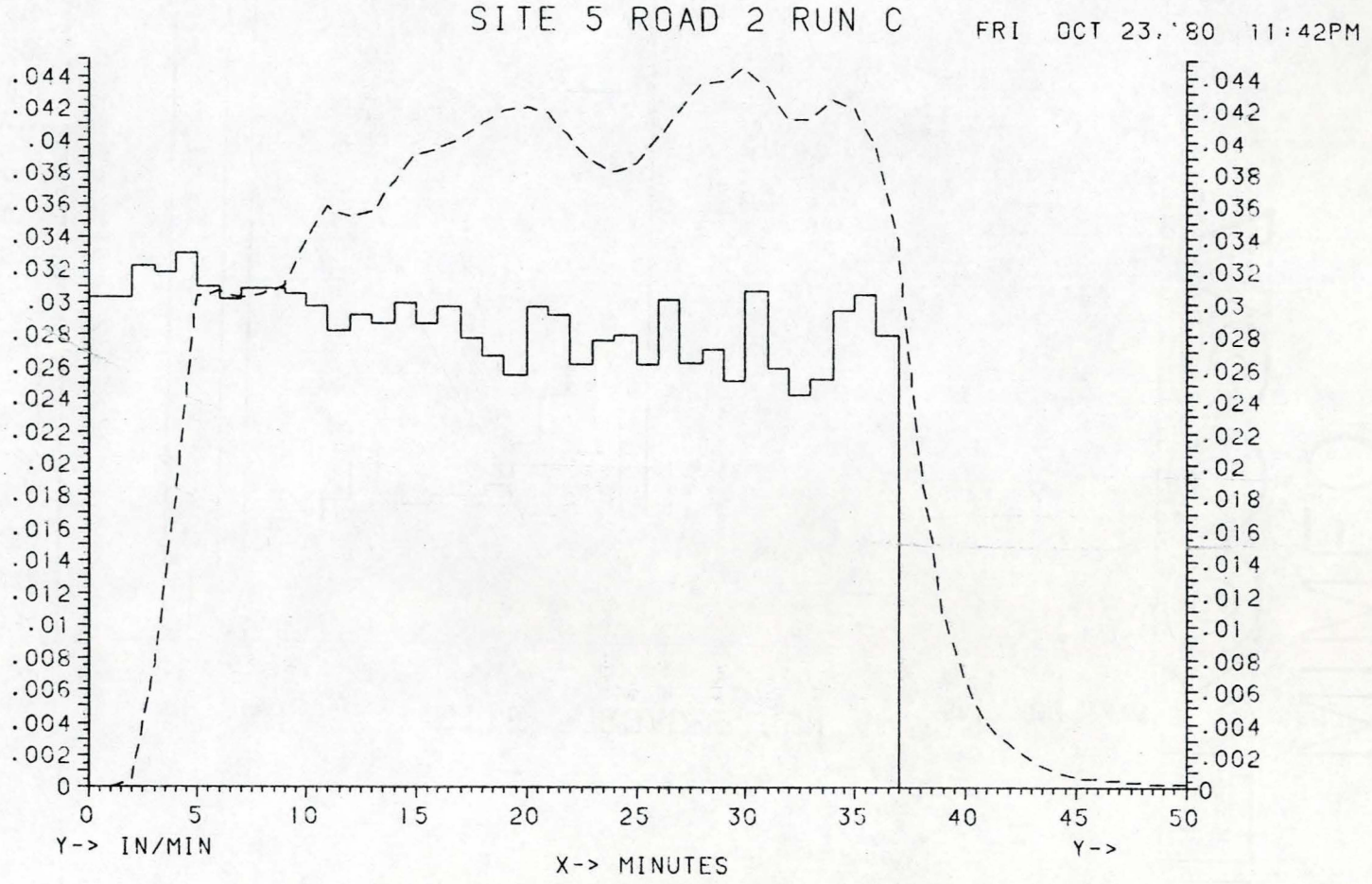

SITE 4 ROAD 1 RUN A
FRI OCT 23,'80 10:17PM
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Y-> IN/MIN
X-> MINUTES
Y->

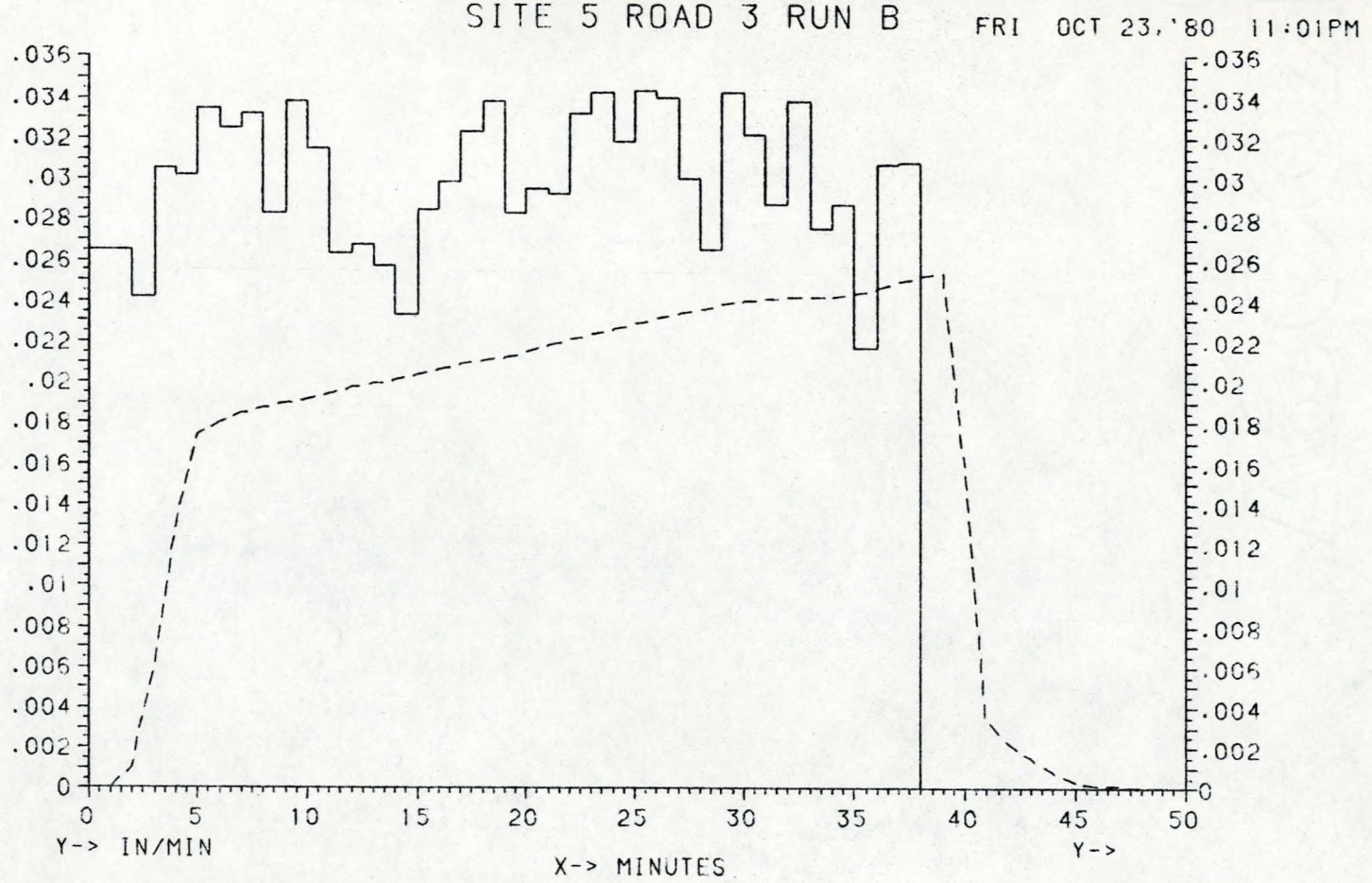

SITE 4 ROAD 2 RUN A
FRI OCT 23, '80 10:28PM
.038
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Y-> IN/MIN
X-> MINUTES
Y->

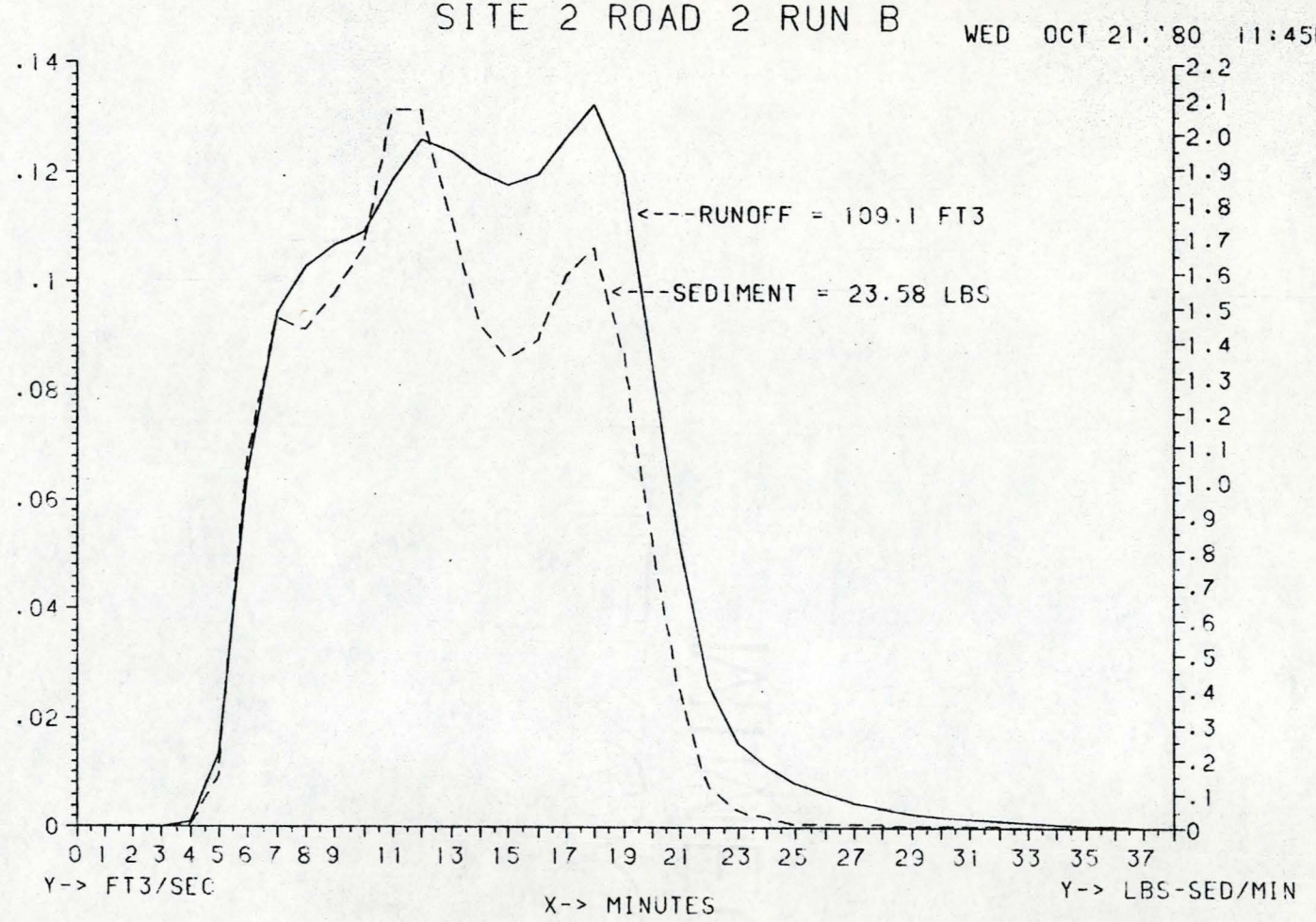

SITE 4 ROAD 2 RUN B
FRI OCT 23,'80 10:36PM
.042
.04
.038
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Y-> IN/MIN
X-> MINUTES
Y->

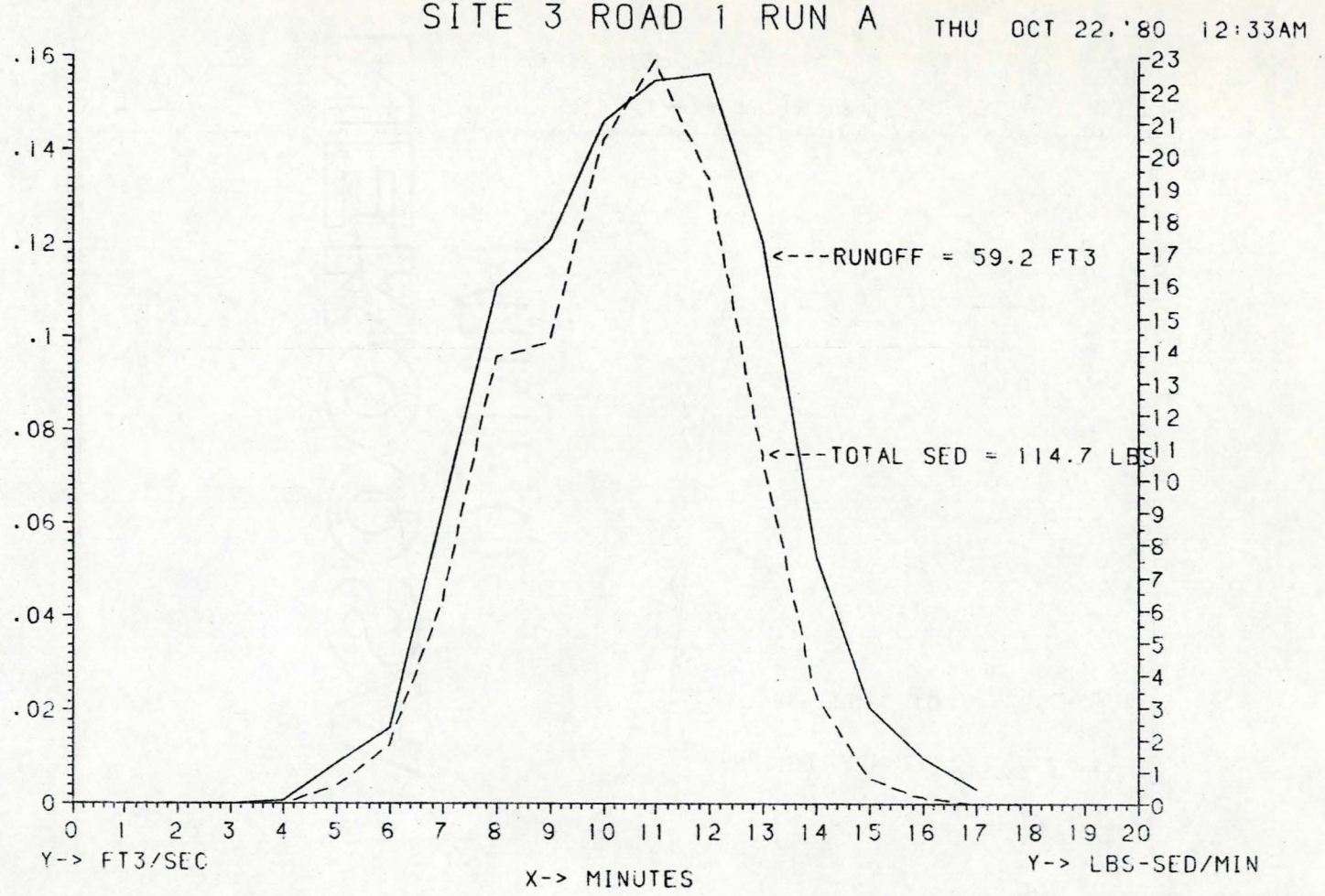

SITE 5 ROAD 1 RUN B
FRI OCT 23,'80 10:45PM
.042
.04
.038
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 5 10 15 20 25 30 35 40 45 50 55
Y-> IN/MIN
X-> MINUTES
Y->

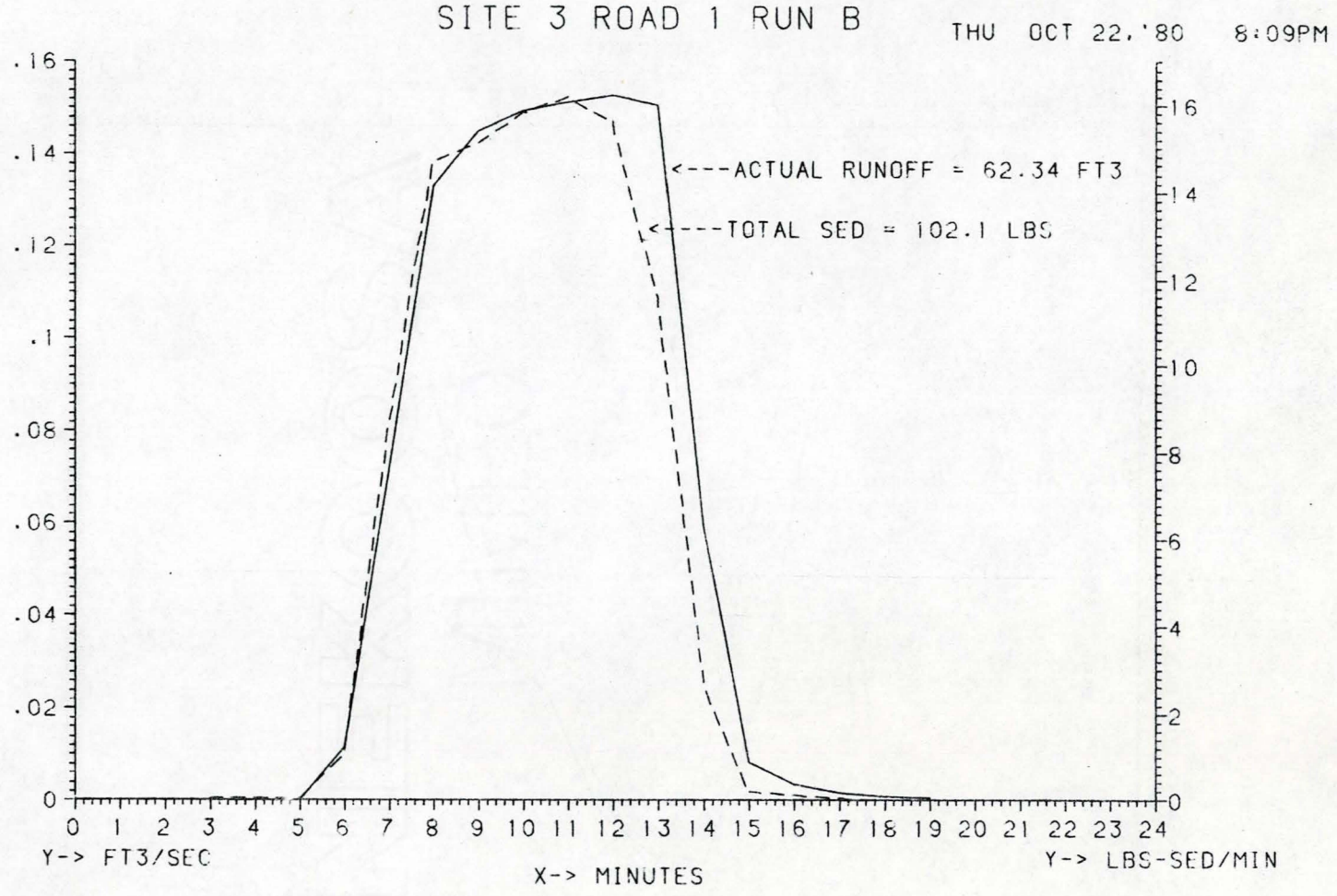

SITE 5 ROAD 2 RUN A
SAT OCT 24,'80 12:16AM
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Y-> IN/MIN
X-> MINUTES
Y->

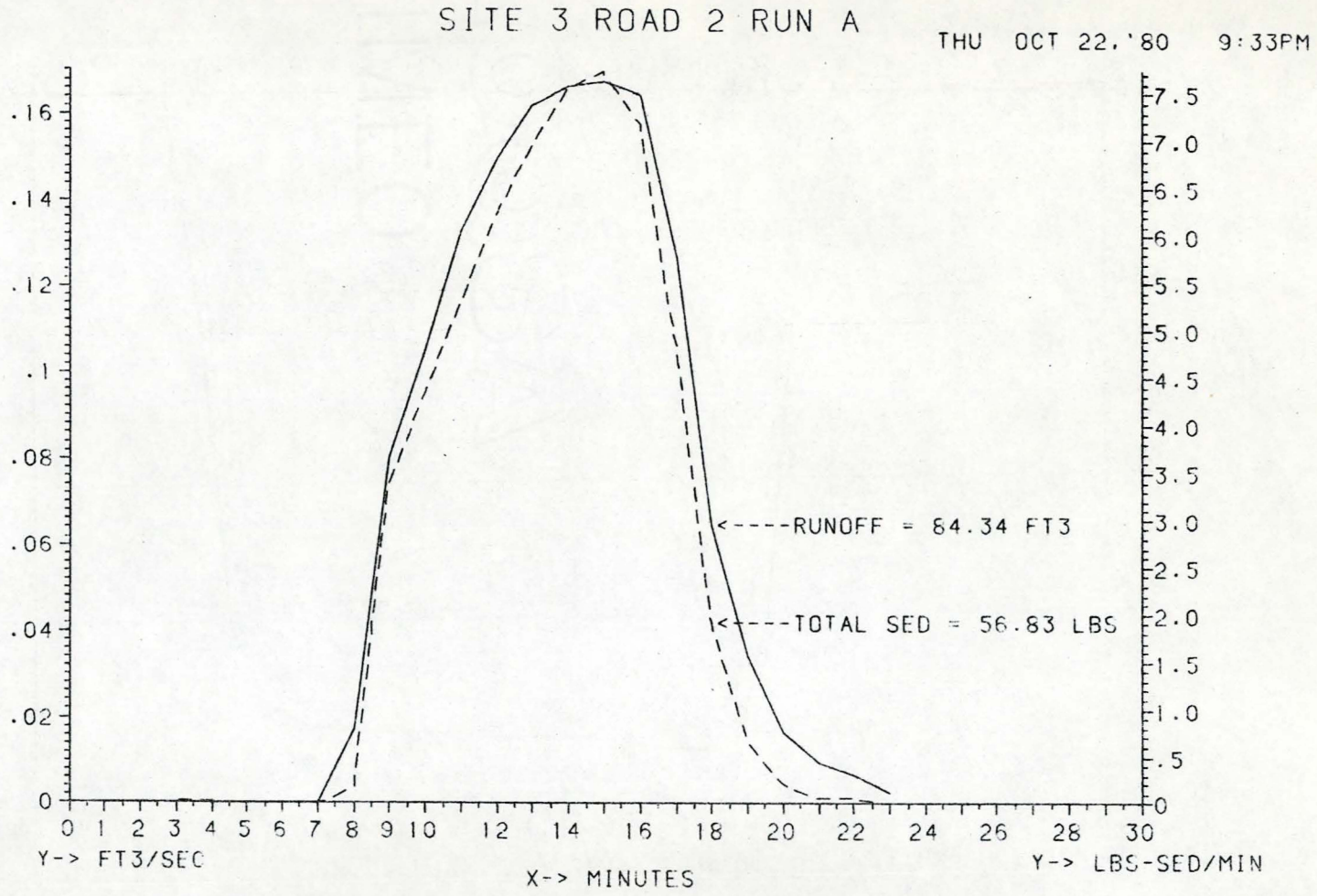

SITE 5 ROAD 2 RUN C
FRI OCT 23,'80 11:42PM
.044
.042
.04
.038
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 5 10 15 20 25 30 35 40 45 50
Y-> IN/MIN
X-> MINUTES
Y->

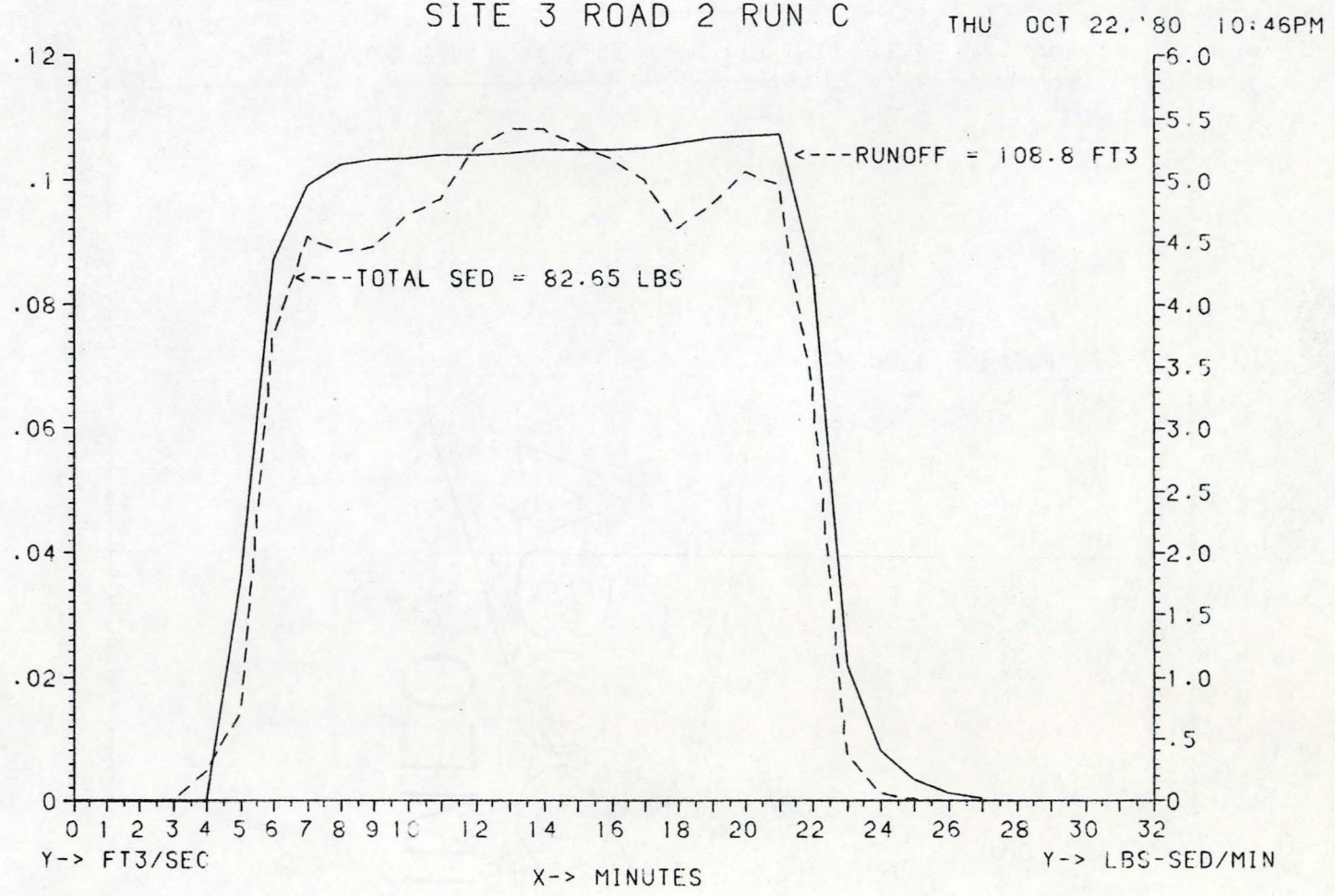

SITE 5 ROAD 3 RUN B
FRI OCT 23,'80 11:01PM
.036
.034
.032
.03
.028
.026
.024
.022
.02
.018
.016
.014
.012
.01
.008
.006
.004
.002
0
0 5 10 15 20 25 30 35 40 45 50
Y-> IN/MIN
X-> MINUTES
Y->

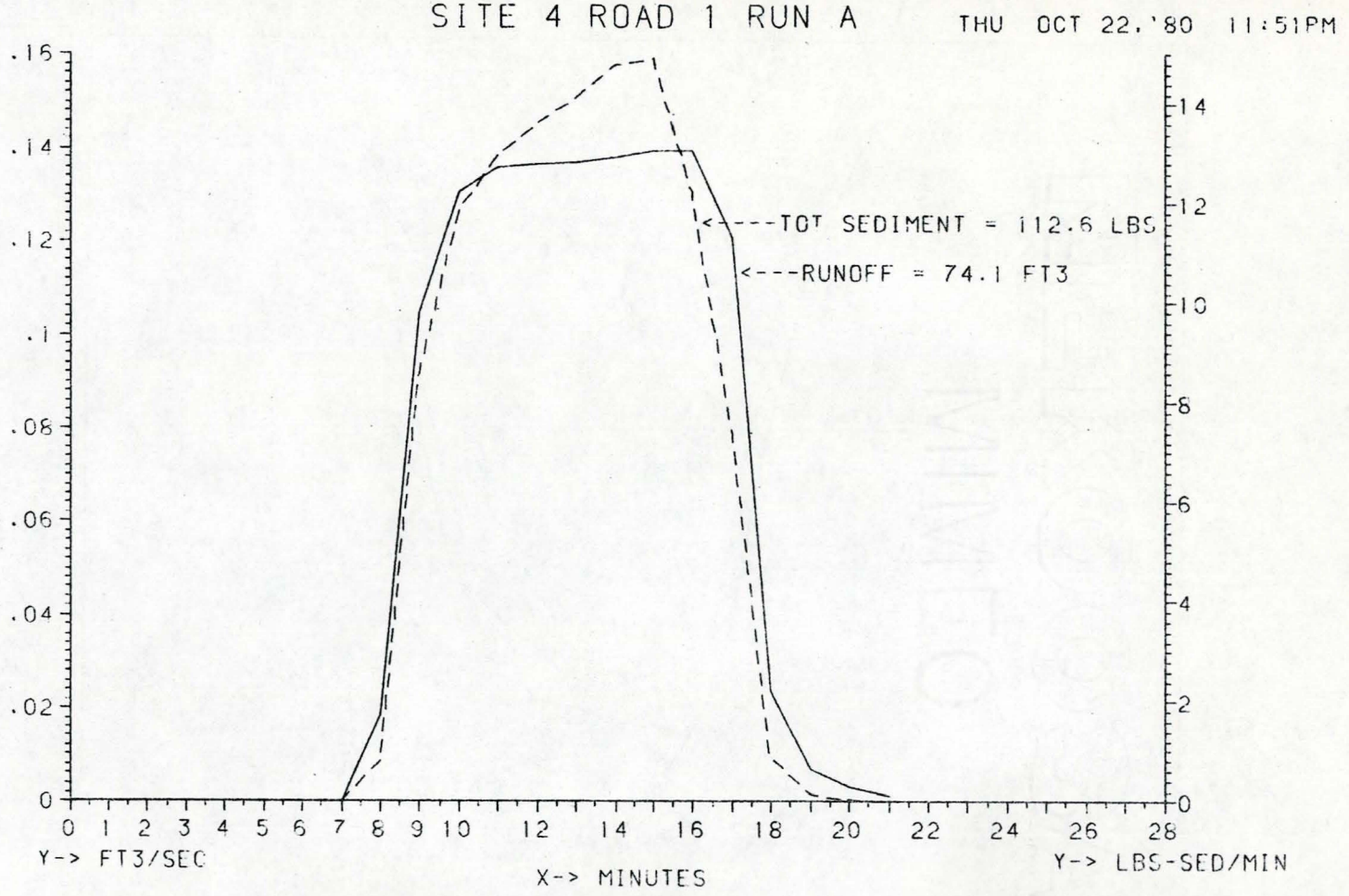

SITE 2 ROAD 2 RUN B
WED OCT 21,'80 11:45PM
<---RUNOFF = 109.1 FT3
<---SEDIMENT = 23.58 LBS
.14
.12
.1
.08
.06
.04
.02
0
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
0 1 2 3 4 5 6 7 8 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

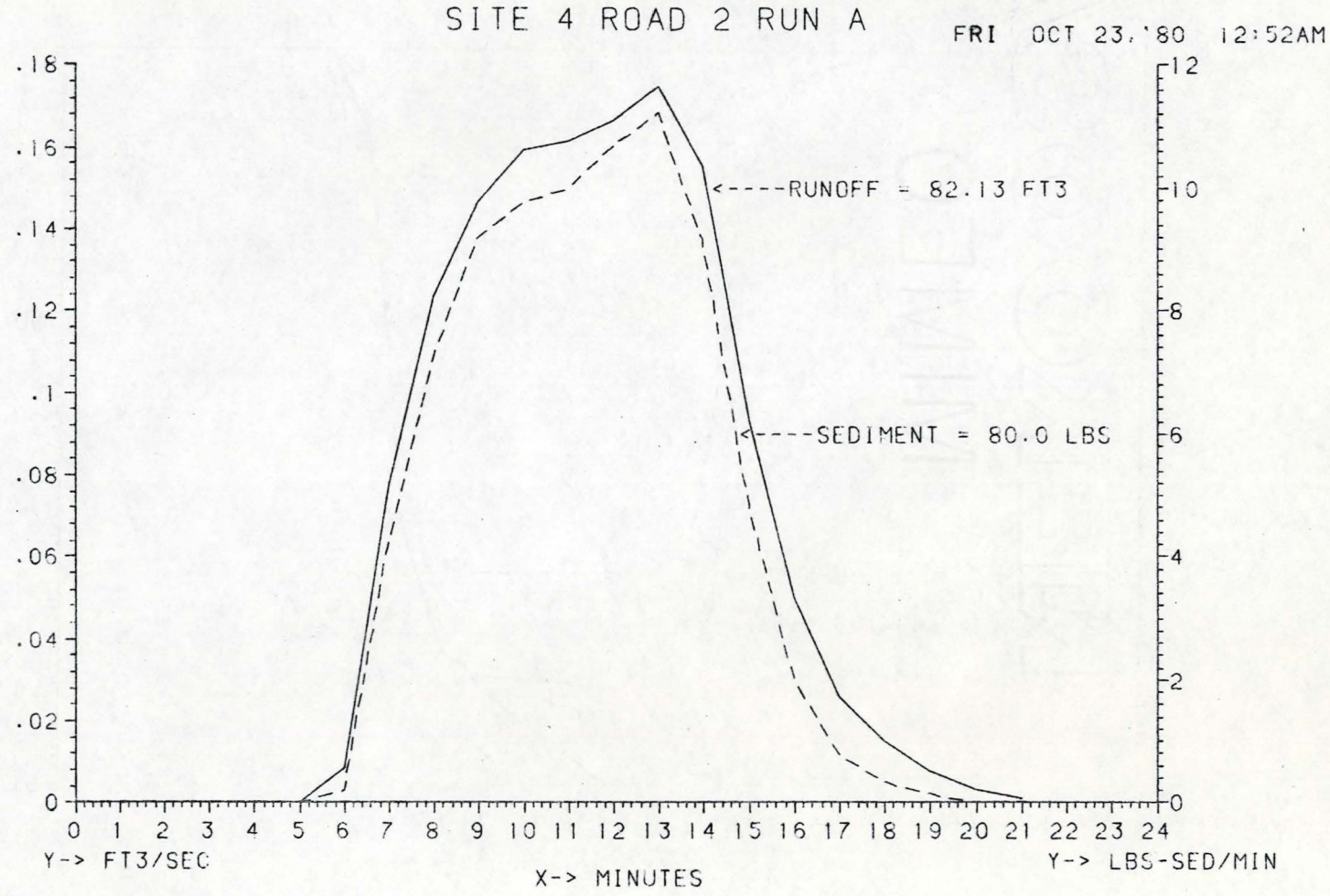

SITE 3 ROAD 1 RUN A
THU OCT 22,'80 12:33AM
<---RUNOFF = 59.2 FT3
<---TOTAL SED = 114.7 LBS
.16
.14
.12
.1
.08
.06
.04
.02
0
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

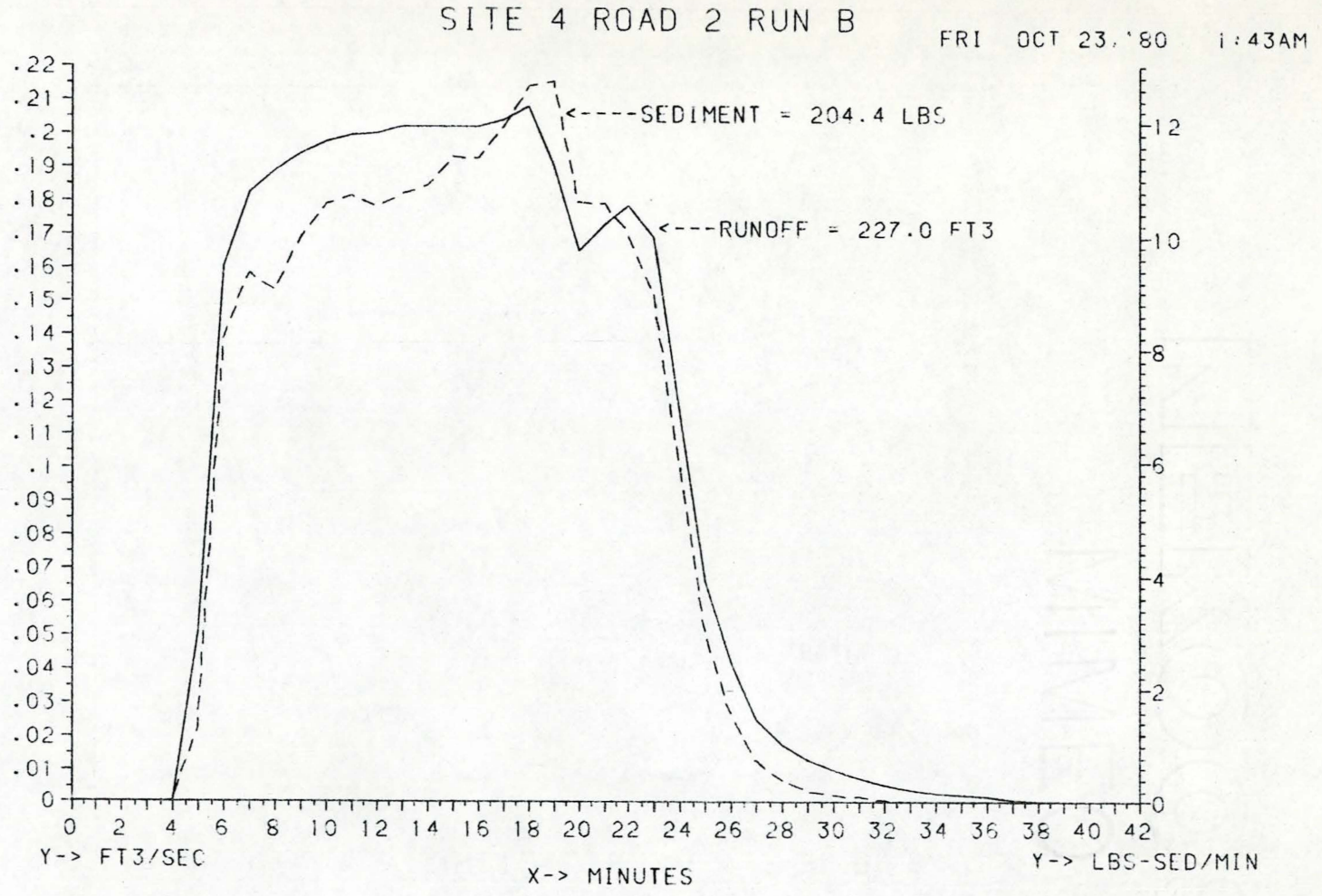

SITE 3 ROAD 1 RUN B
THU OCT 22,'80 8:09PM
<---ACTUAL RUNOFF = 62.34 FT3
<---TOTAL SED = 102.1 LBS
.16
.14
.12
.1
.08
.06
.04
.02
0
16
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

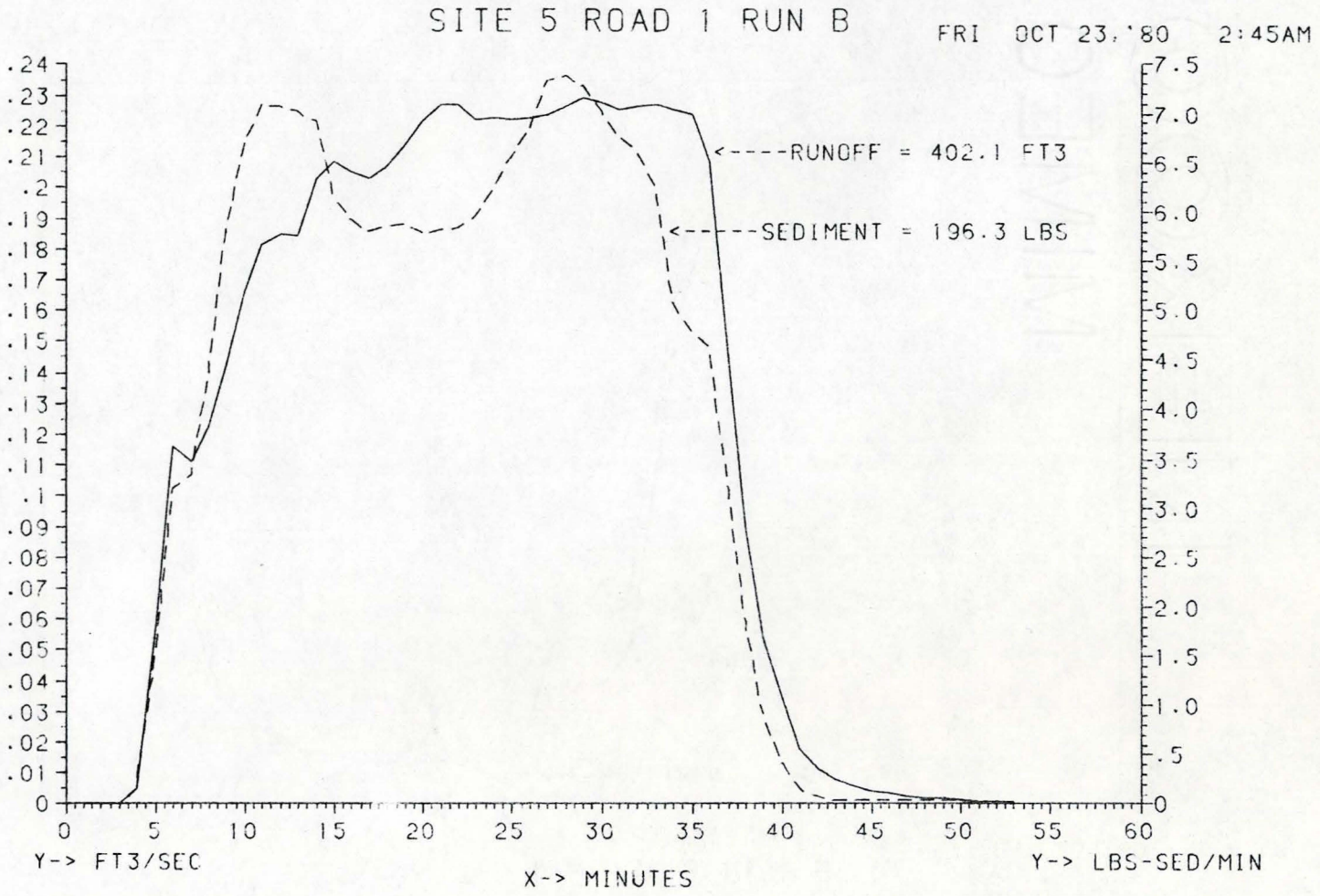

SITE 3 ROAD 2 RUN A
THU OCT 22,'80 9:33PM
.16
.14
.12
.1
.08
.06
.04
.02
0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28 30
<----RUNOFF = 84.34 FT3
<----TOTAL SED = 56.83 LBS
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

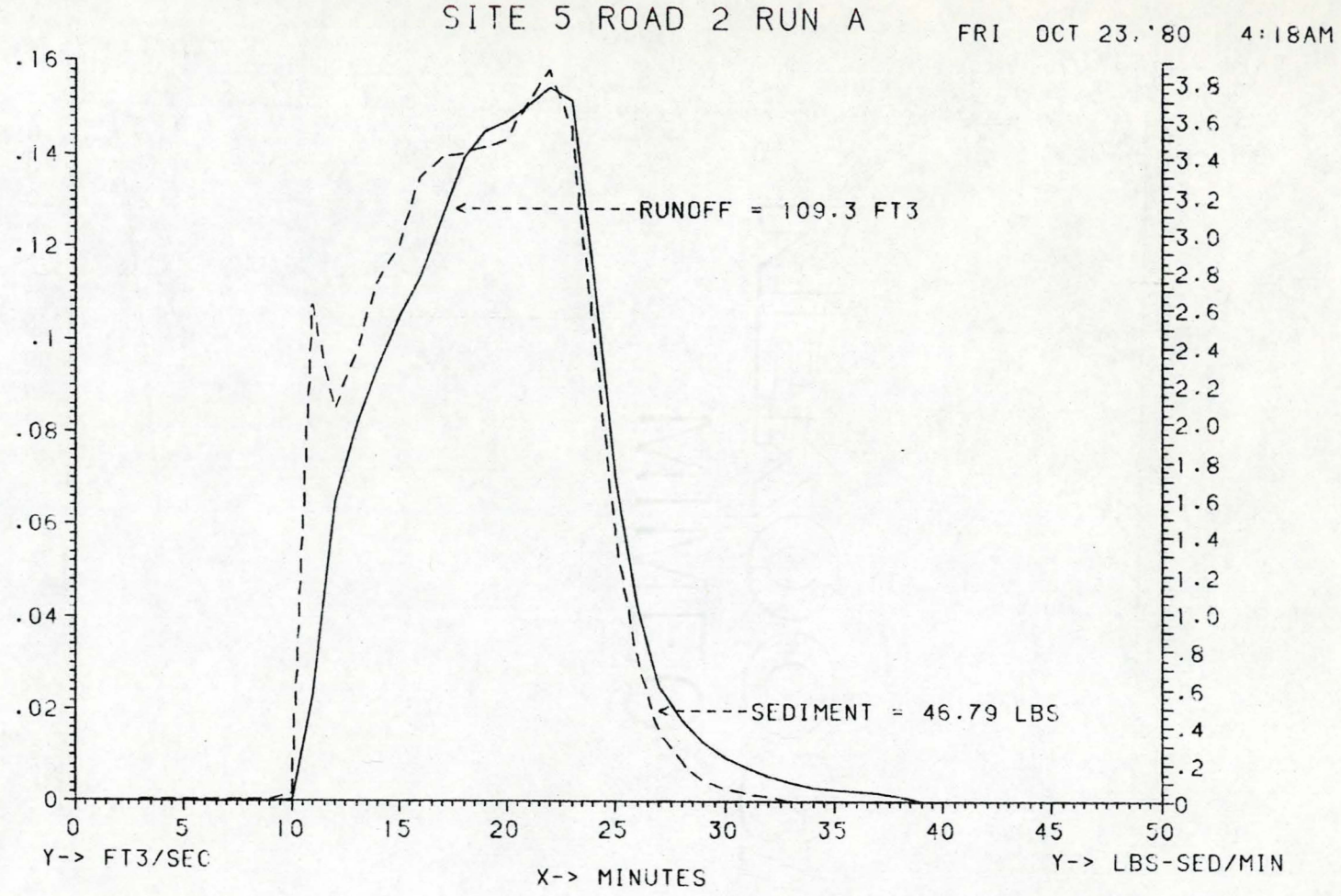

SITE 3 ROAD 2 RUN C
THU OCT 22,'80 10:46PM
<---RUNOFF = 108.8 FT3
<---TOTAL SED = 82.65 LBS
.12
.1
.08
.06
.04
.02
0
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28 30 32
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

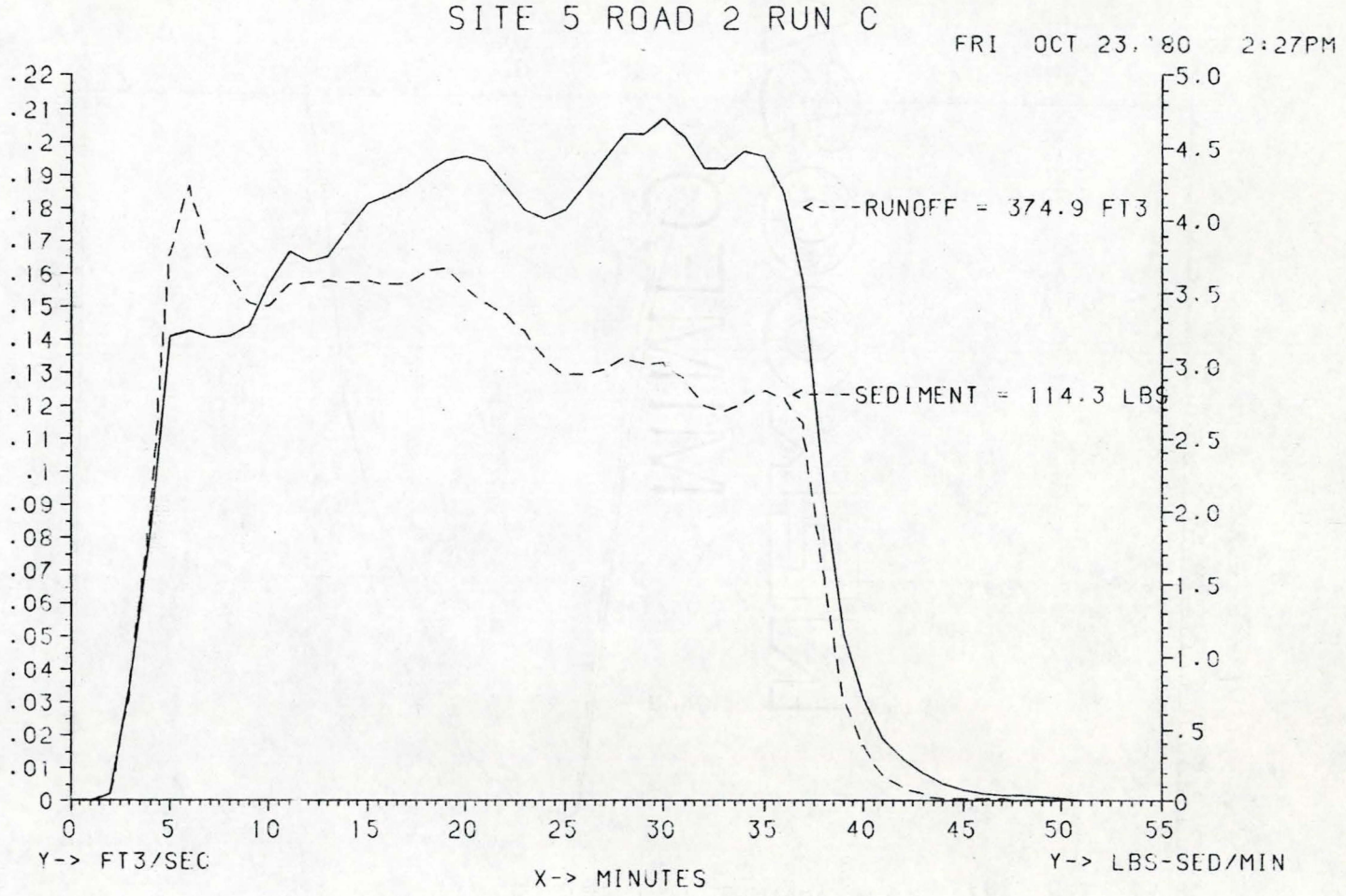

SITE 4 ROAD 1 RUN A
THU OCT 22,'80 11:51PM
<----TOT SEDIMENT = 112.6 LBS
<---RUNOFF = 74.1 FT3
.16
.14
.12
.1
.08
.06
.04
.02
0
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

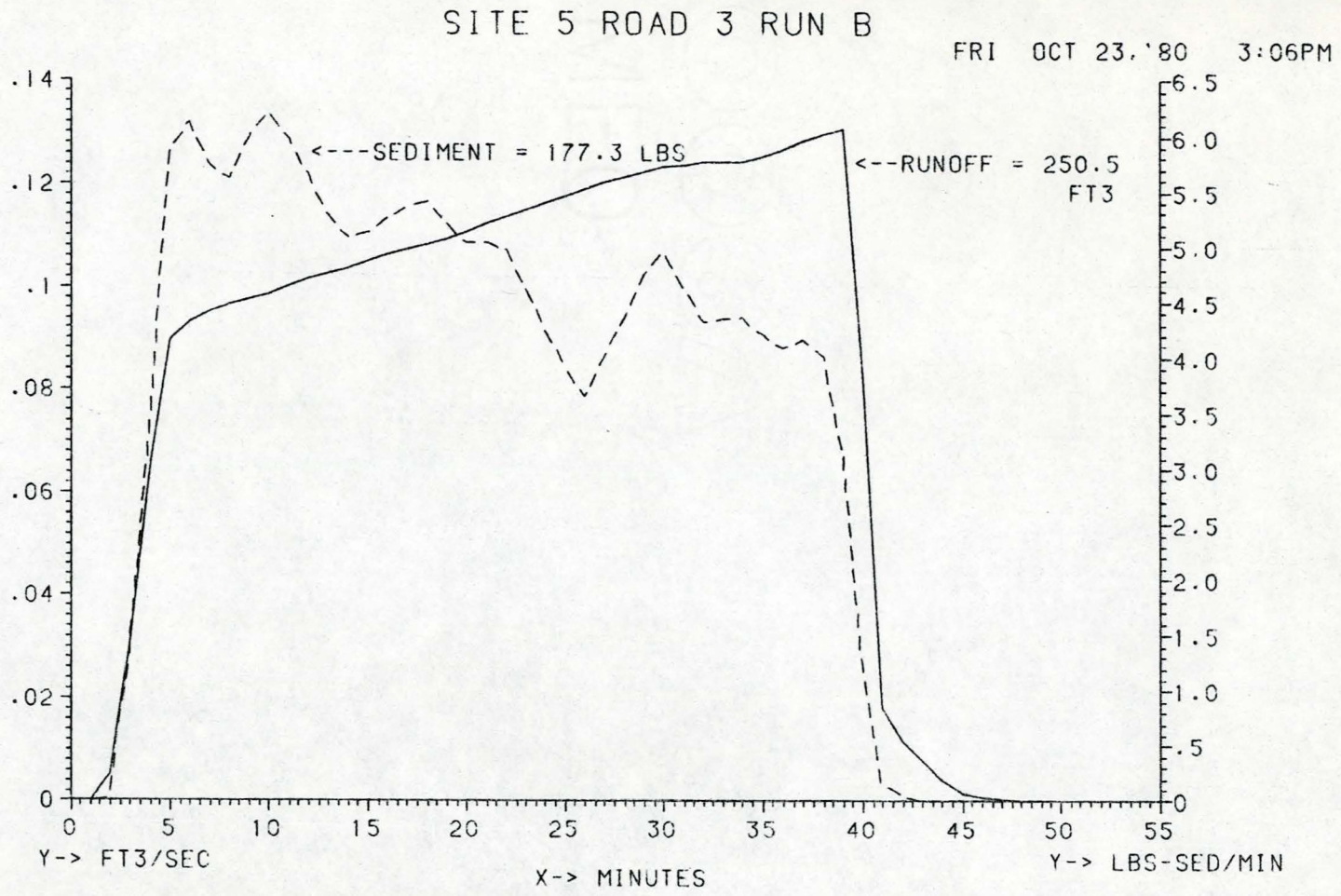

SITE 4 ROAD 2 RUN A
FRI OCT 23, '80 12:52AM
<----RUNOFF = 82.13 FT3
<----SEDIMENT = 80.0 LBS
.18
.16
.14
.12
.1
.08
.06
.04
.02
0
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

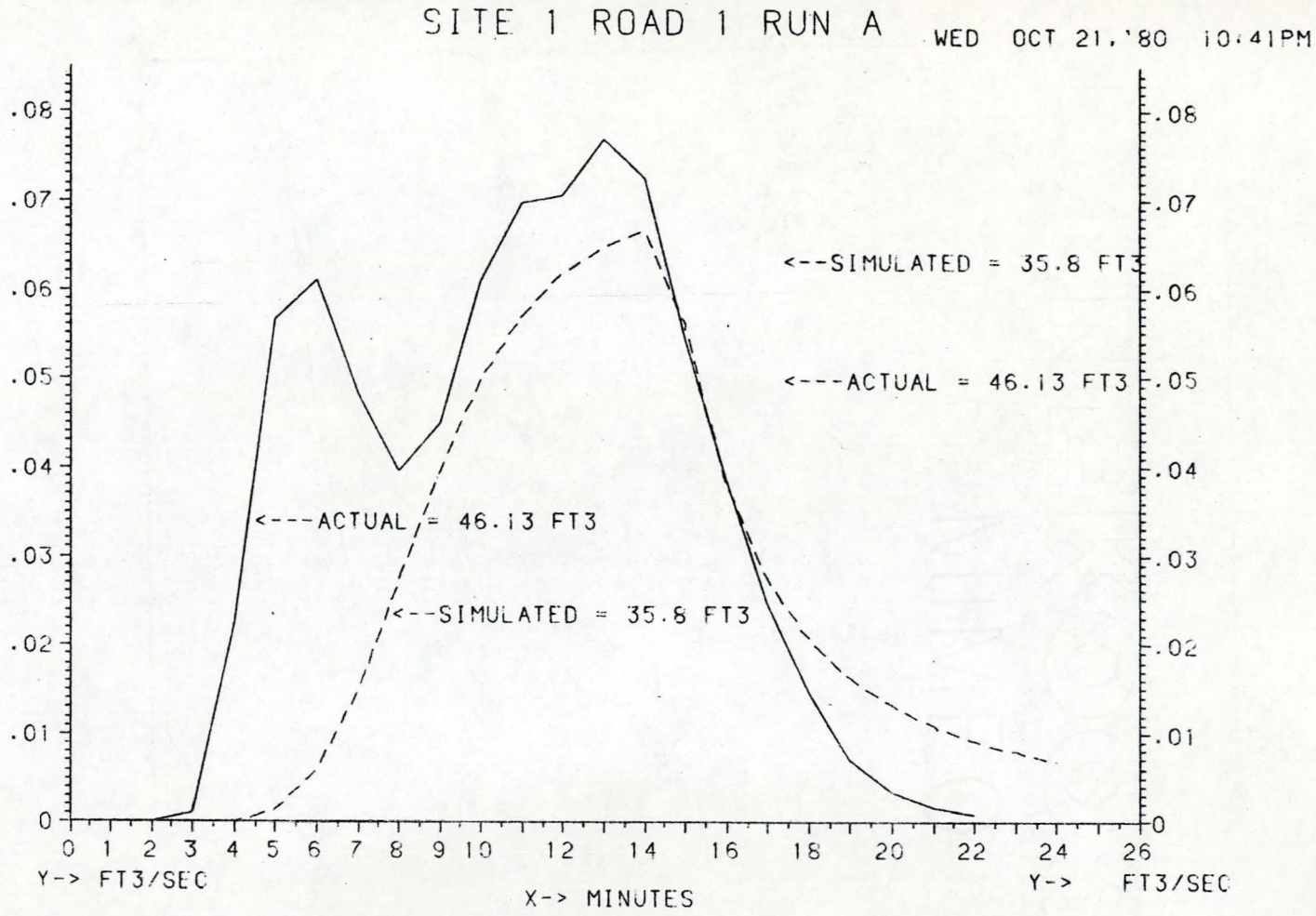

SITE 4 ROAD 2 RUN B
FRI OCT 23, '80 1:43AM
<----SEDIMENT = 204.4 LBS
<---RUNOFF = 227.0 FT3
.22
.21
.2
.19
.18
.17
.16
.15
.14
.13
.12
.11
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
12
10
8
6
4
2
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

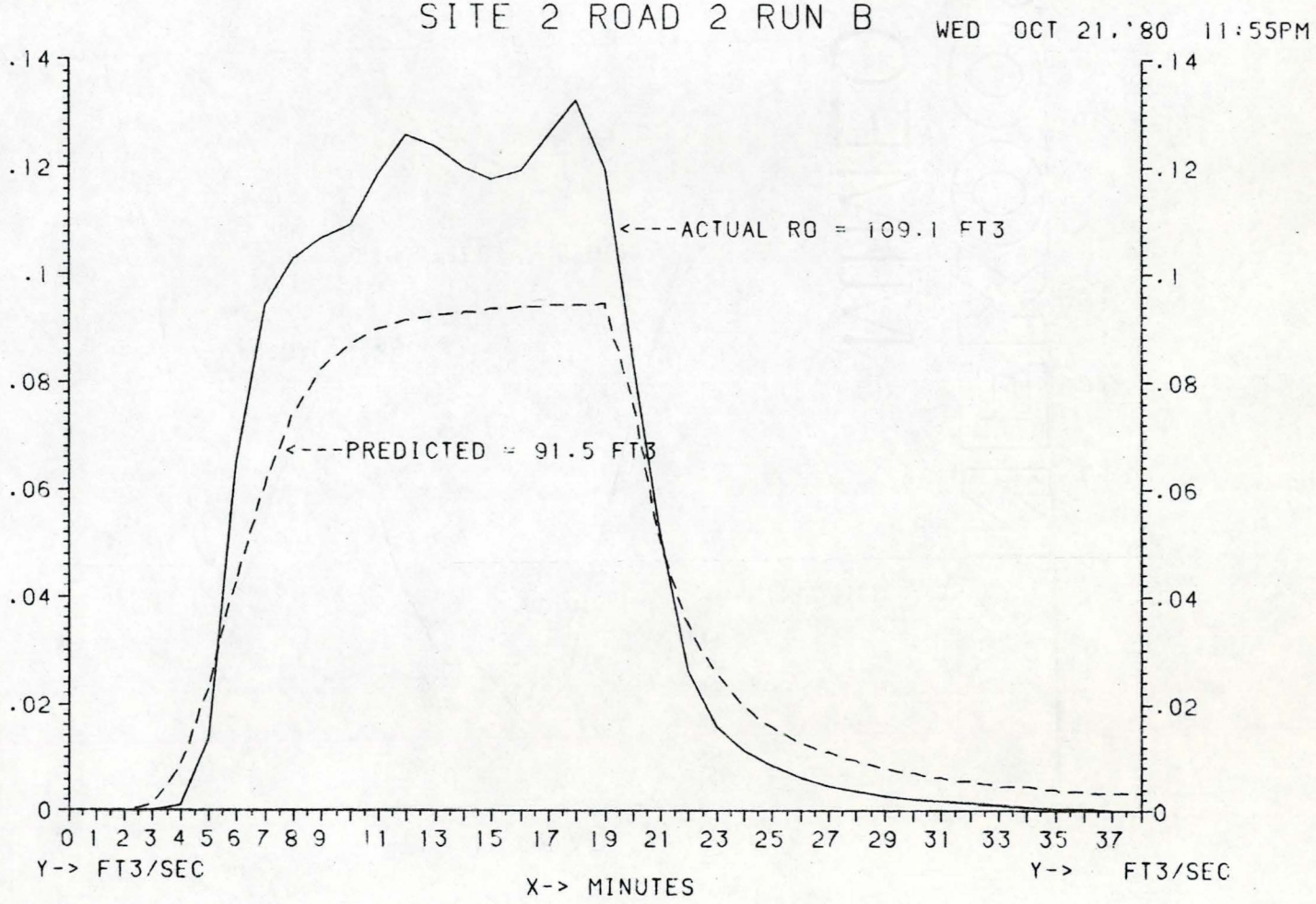

SITE 5 ROAD 1 RUN B
FRI OCT 23, '80 2:45AM
<----RUNOFF = 402.1 FT3
<----SEDIMENT = 196.3 LBS
.24
.23
.22
.21
.2
.19
.18
.17
.16
.15
.14
.13
.12
.11
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0 5 10 15 20 25 30 35 40 45 50 55 60
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

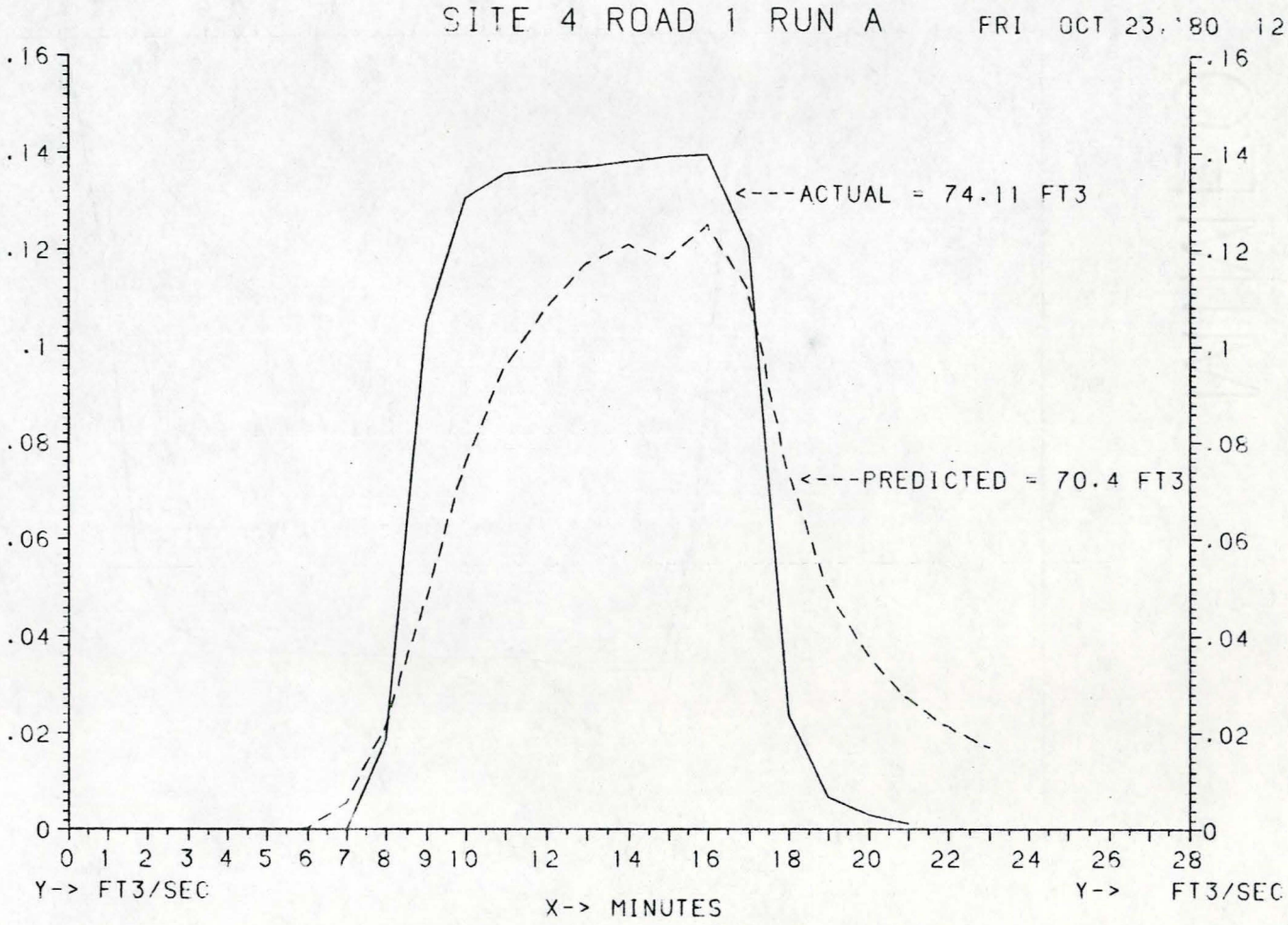

SITE 5 ROAD 2 RUN A
FRI OCT 23, '80 4:18AM
RUNOFF = 109.3 FT3
SEDIMENT = 46.79 LBS
.16
.14
.12
.1
.08
.06
.04
.02
0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
0 5 10 15 20 25 30 35 40 45 50
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

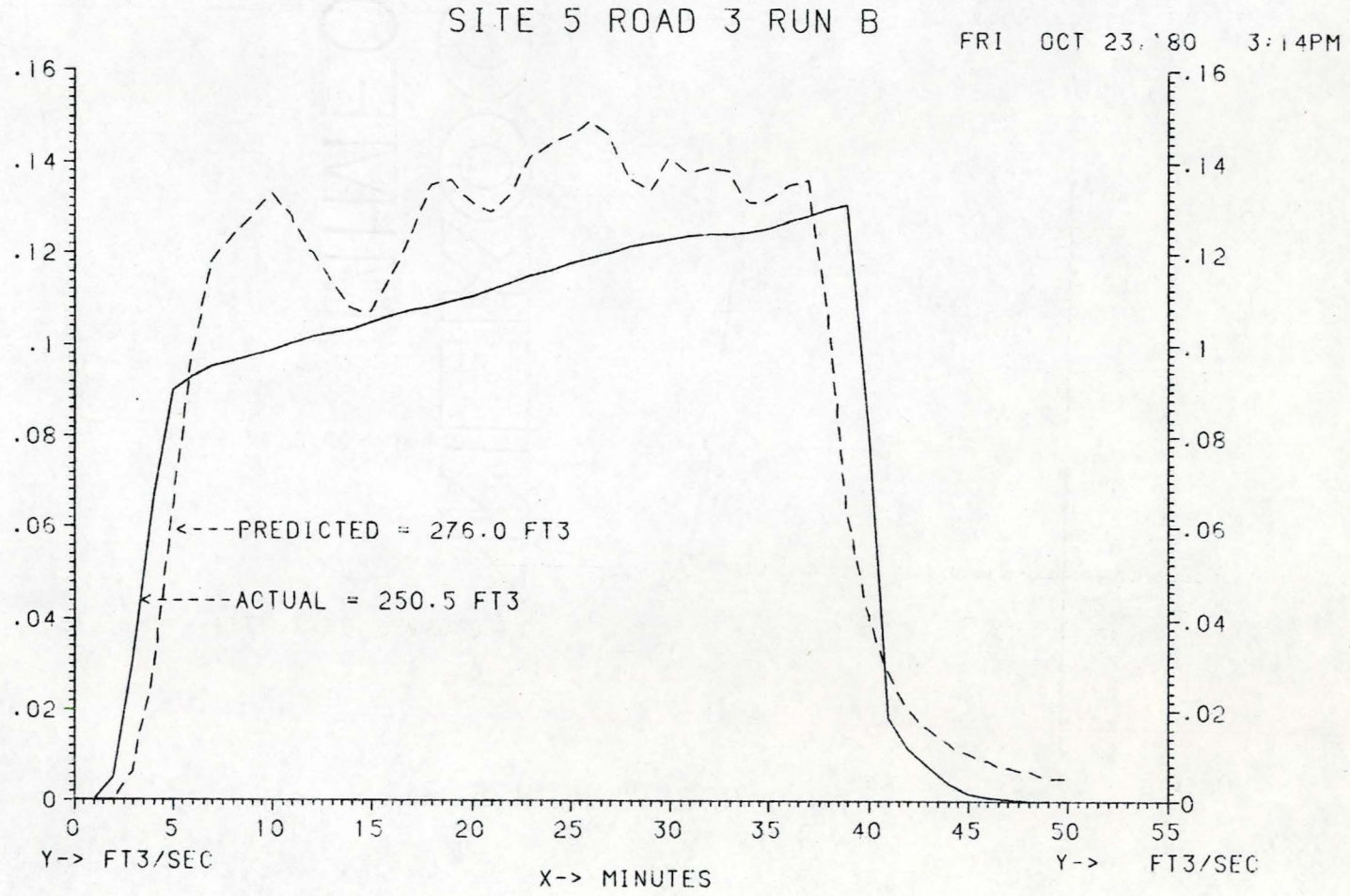

SITE 5 ROAD 2 RUN C
FRI OCT 23, '80 2:27PM
<---RUNOFF = 374.9 FT3
<---SEDIMENT = 114.3 LBS
.22
.21
.2
.19
.18
.17
.16
.15
.14
.13
.12
.11
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0 5 10 15 20 25 30 35 40 45 50 55
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

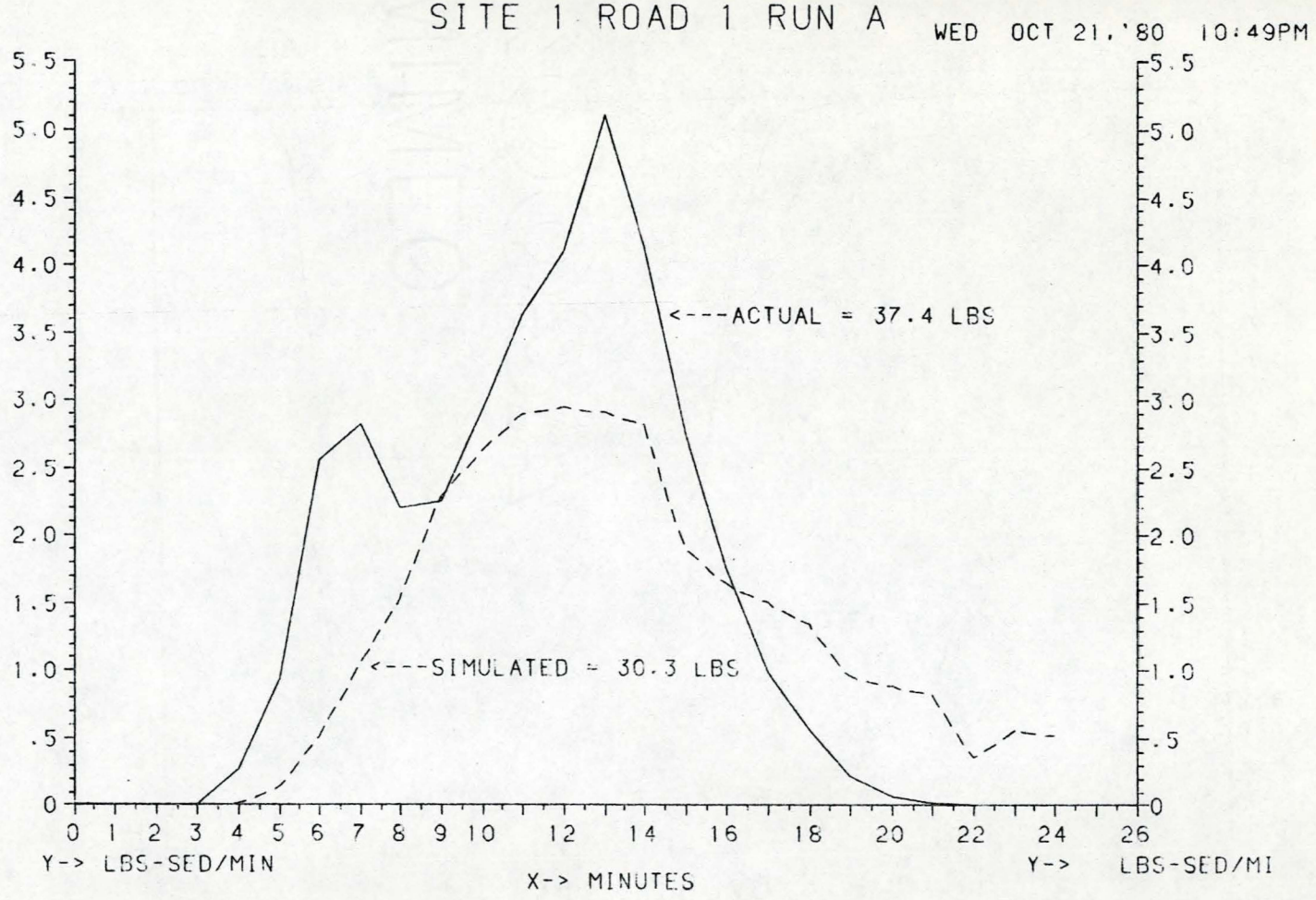

SITE 5 ROAD 3 RUN B
FRI OCT 23,'80 3:06PM
<---SEDIMENT = 177.3 LBS
<--RUNOFF = 250.5 FT3
.14
.12
.1
.08
.06
.04
.02
0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
0 5 10 15 20 25 30 35 40 45 50 55
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MIN

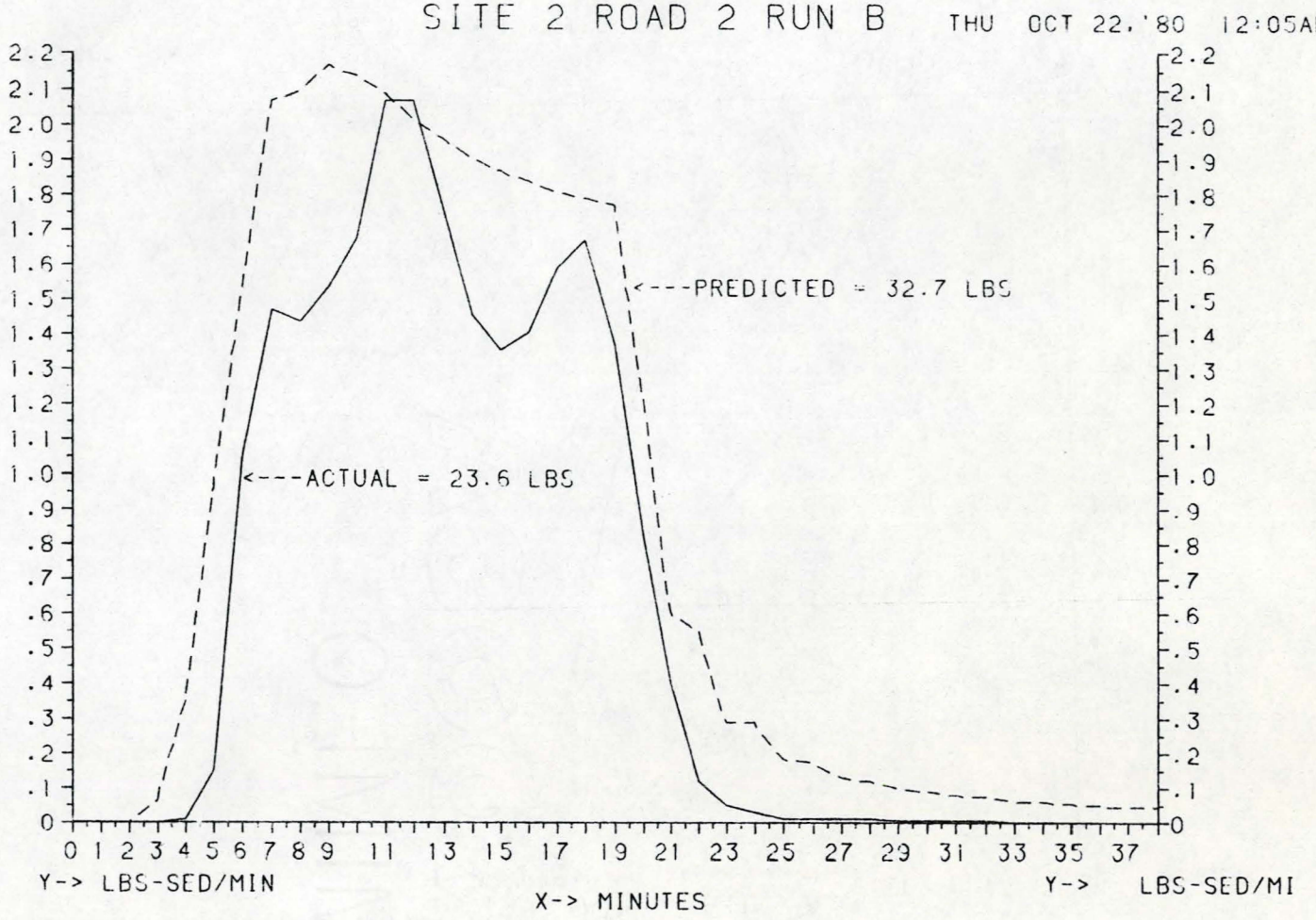

SITE 1 ROAD 1 RUN A
WED OCT 21,'80 10:41PM
.08
.07
.06
.05
.04
.03
.02
.01
0
<---ACTUAL = 46.13 FT3
<--SIMULATED = 35.8 FT3
<--SIMULATED = 35.8 FT3
<---ACTUAL = 46.13 FT3
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

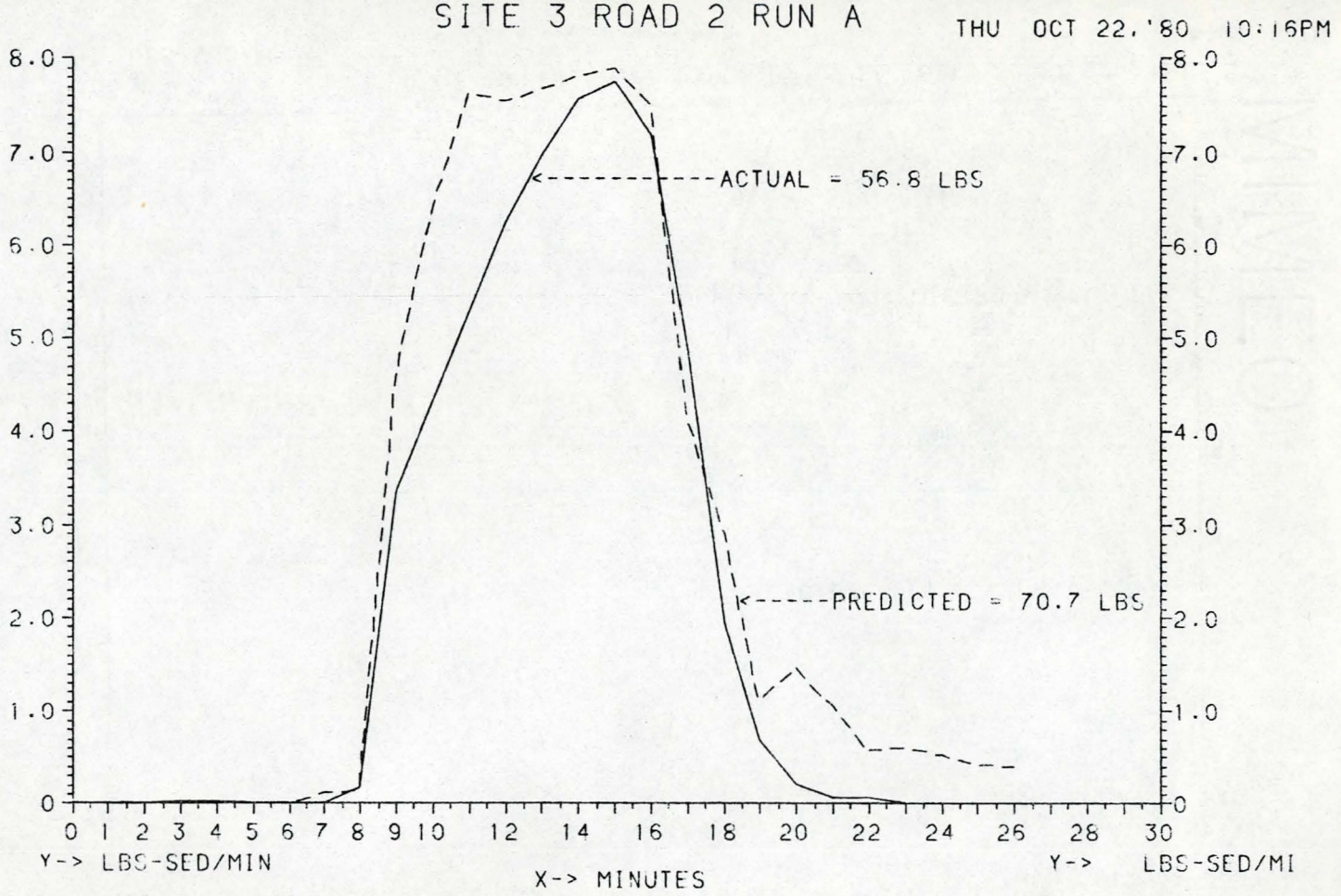

SITE 2 ROAD 2 RUN B
WED OCT 21,'80 11:55PM
<---ACTUAL RO = 109.1 FT3
<---PREDICTED = 91.5 FT3
.14
.12
.1
.08
.06
.04
.02
0
0 1 2 3 4 5 6 7 8 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

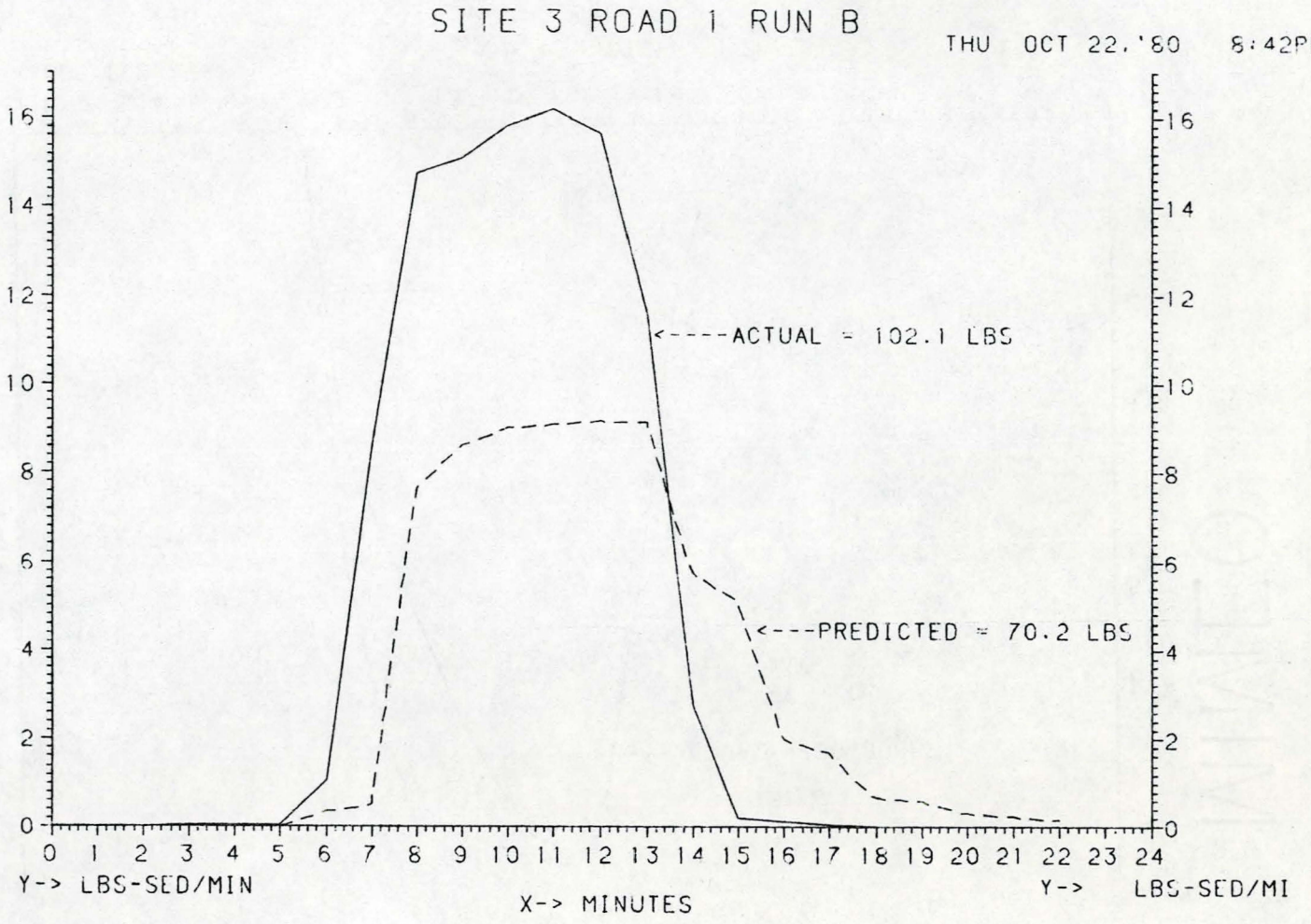

SITE 4 ROAD 1 RUN A
FRI OCT 23, '80 12:15AM
<---ACTUAL = 74.11 FT3
<---PREDICTED = 70.4 FT3
.16
.14
.12
.1
.08
.06
.04
.02
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

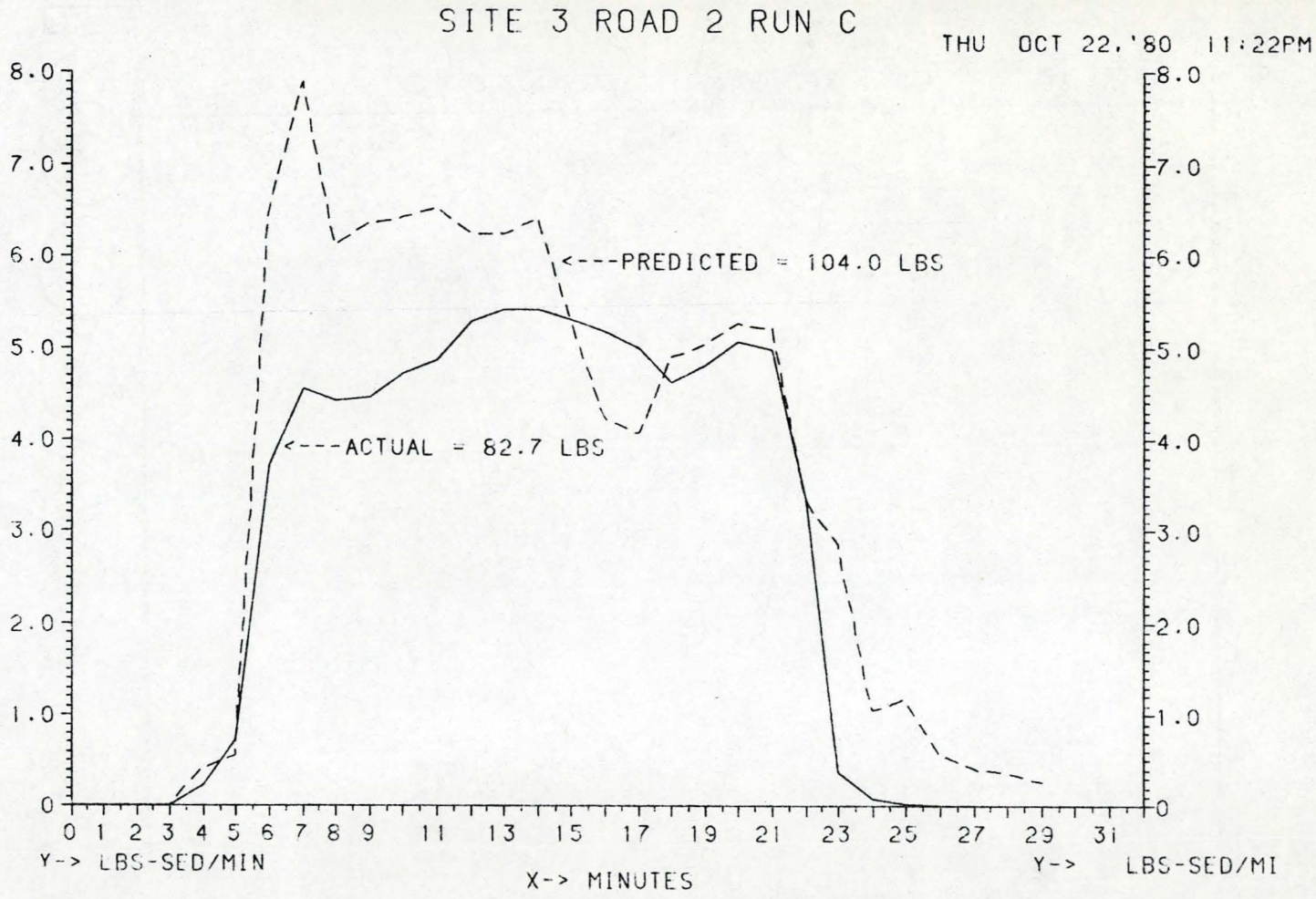

SITE 5 ROAD 3 RUN B
FRI OCT 23, '80 3:14PM
.16
.14
.12
.1
.08
.06
.04
.02
0
<---PREDICTED = 276.0 FT3
<----ACTUAL = 250.5 FT3
0 5 10 15 20 25 30 35 40 45 50 55
Y-> FT3/SEC
X-> MINUTES
Y-> FT3/SEC

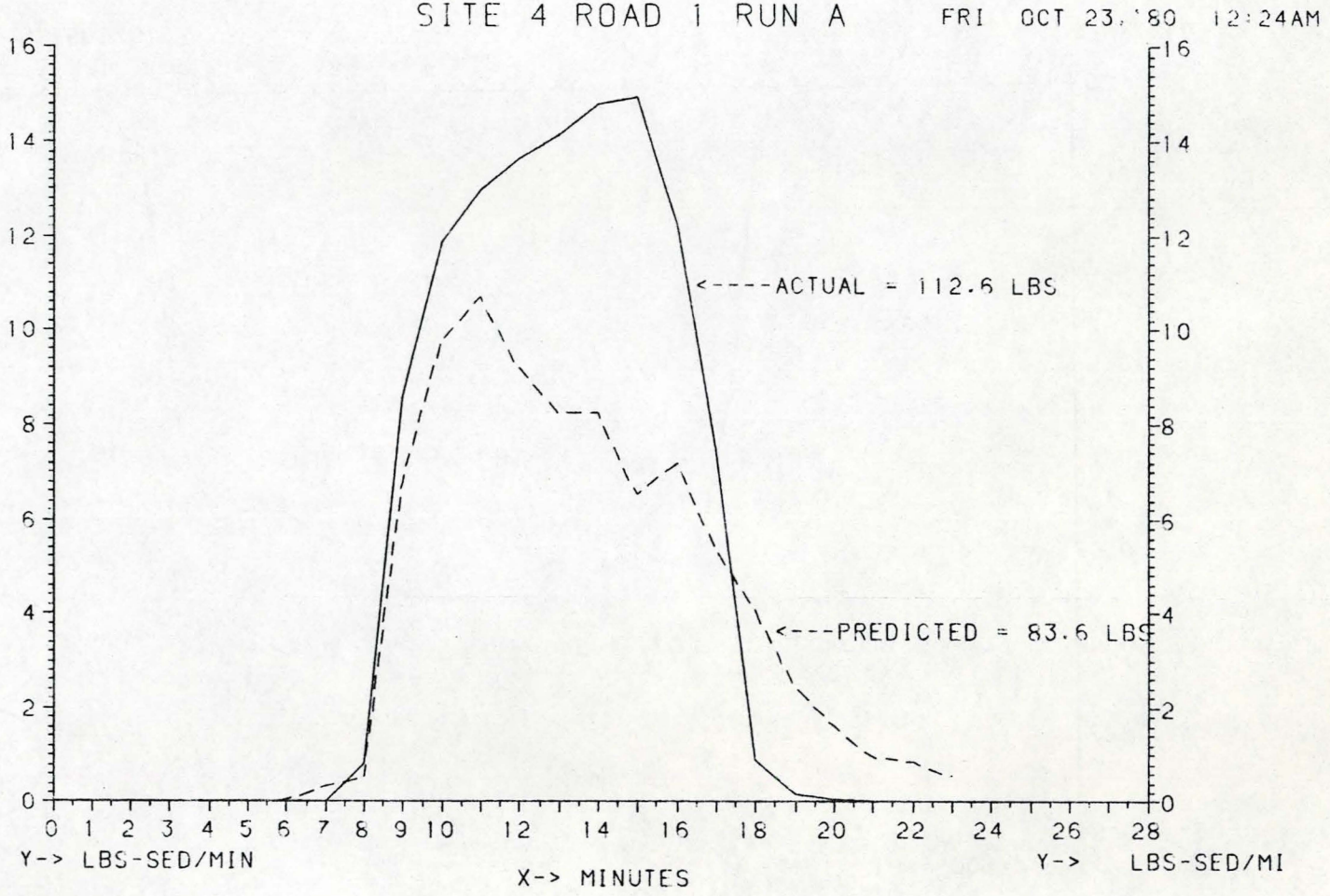

SITE 1 ROAD 1 RUN A
WED OCT 21,'80 10:49PM
<---ACTUAL = 37.4 LBS
<---SIMULATED = 30.3 LBS
Y-> LBS-SED/MIN
X-> MINUTES
Y-> LBS-SED/MI

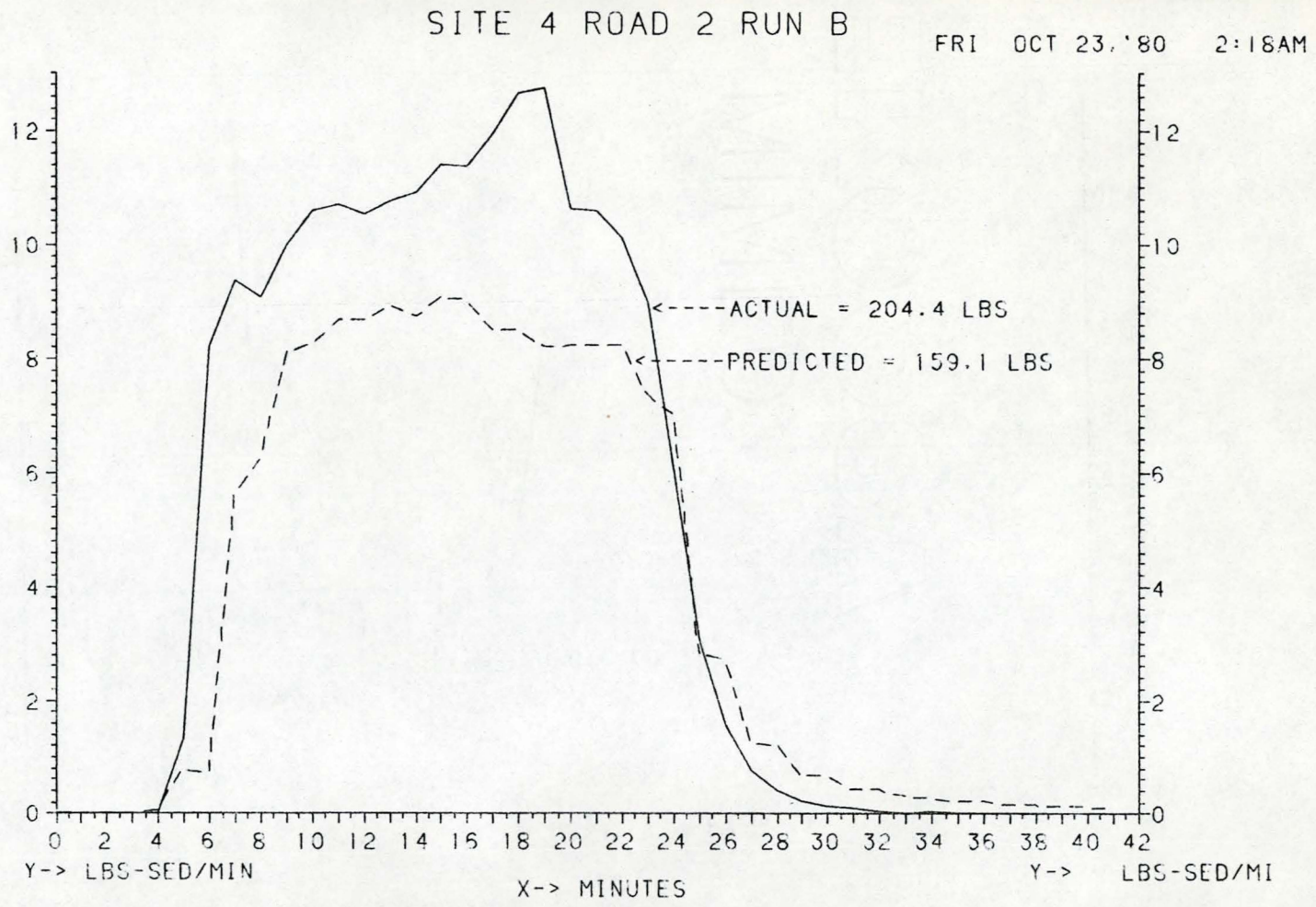

SITE 2 ROAD 2 RUN B
THU OCT 22,'80 12:05AM
<---PREDICTED = 32.7 LBS
<---ACTUAL = 23.6 LBS
Y-> LBS-SED/MIN
X-> MINUTES
Y-> LBS-SED/MI

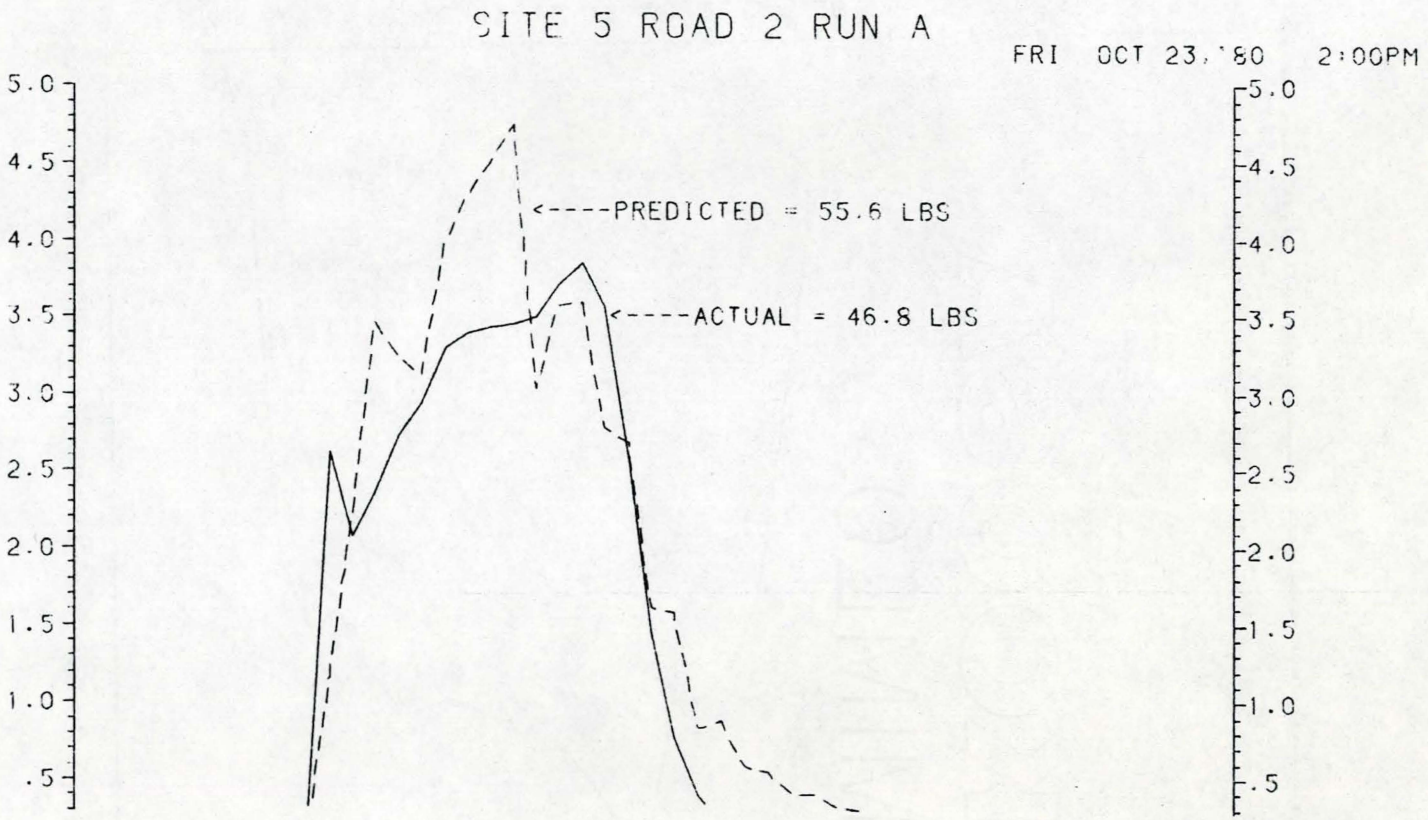

SITE 3 ROAD 2 RUN A
THU OCT 22,'80 10:16PM
ACTUAL = 56.8 LBS
PREDICTED = 70.7 LBS
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28 30
Y-> LBS-SED/MIN
X-> MINUTES
Y-> LBS-SED/MI

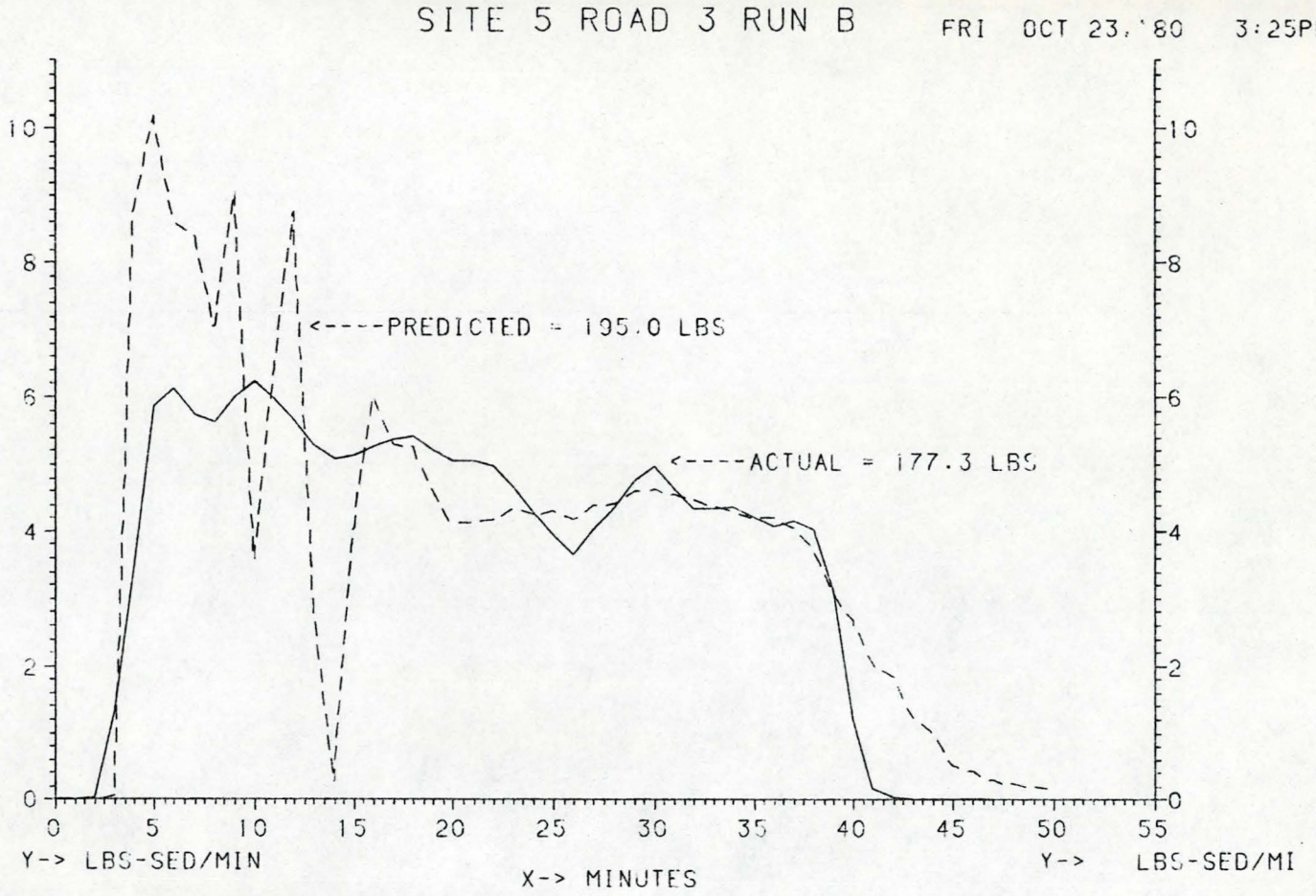

SITE 3 ROAD 1 RUN B
THU OCT 22,'80 8:42PM
<----ACTUAL = 102.1 LBS
<---PREDICTED = 70.2 LBS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Y-> LBS-SED/MIN
X-> MINUTES
Y-> LBS-SED/MI

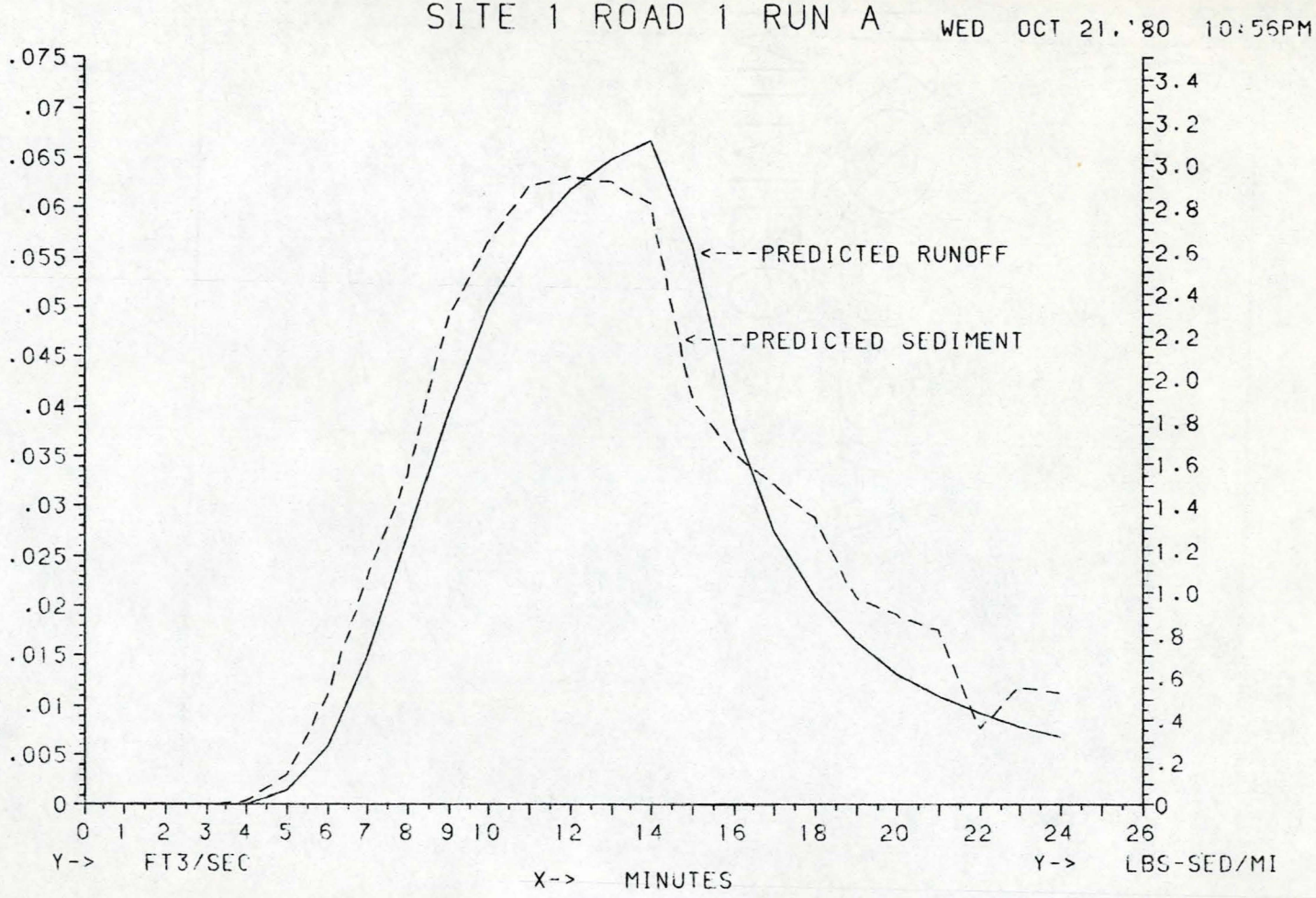

SITE 3 ROAD 2 RUN C
THU OCT 22,'80 11:22PM
<---PREDICTED = 104.0 LBS
<---ACTUAL = 82.7 LBS
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0 1 2 3 4 5 6 7 8 9 11 13 15 17 19 21 23 25 27 29 31
Y-> LBS-SED/MIN
X-> MINUTES
Y-> LBS-SED/MI

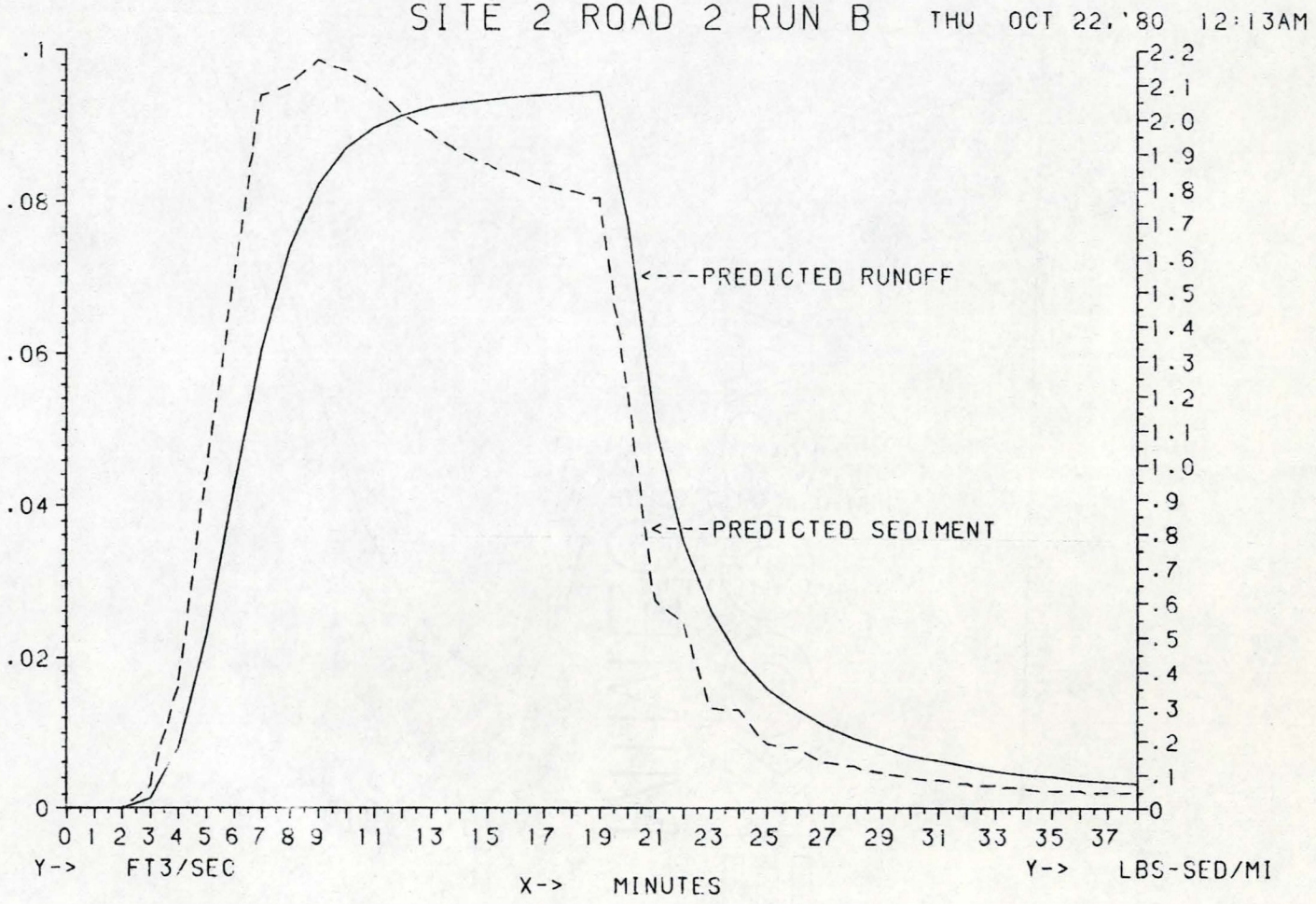

SITE 4 ROAD 1 RUN A
FRI OCT 23, '80 12:24AM
<----ACTUAL = 112.6 LBS
<---PREDICTED = 83.6 LBS
Y-> LBS-SED/MIN
X-> MINUTES
Y-> LBS-SED/MI

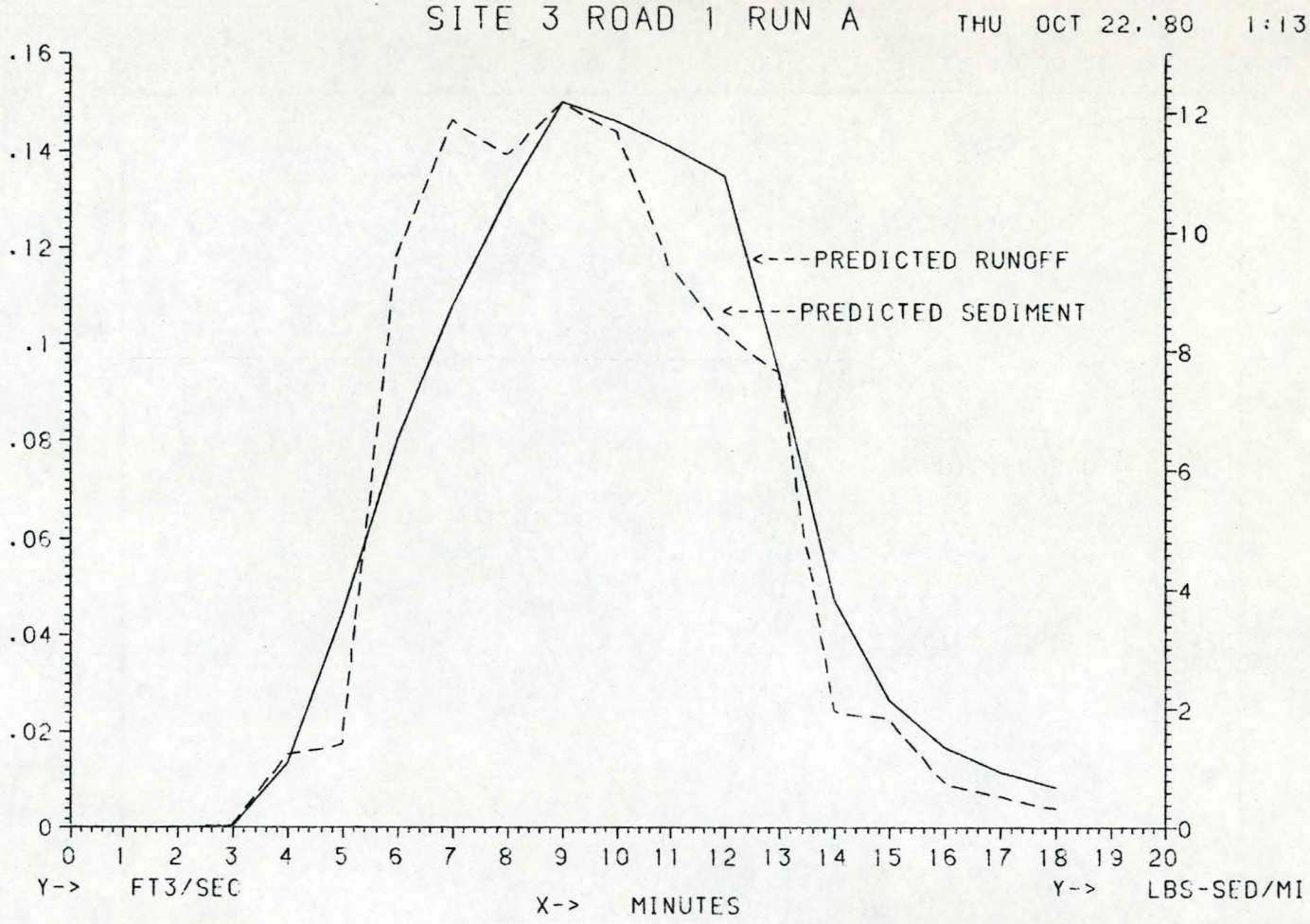

SITE 4 ROAD 2 RUN B
FRI OCT 23, '80 2:18AM
----ACTUAL = 204.4 LBS
----PREDICTED = 159.1 LBS
0 2 4 6 8 10 12
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
Y-> LBS-SED/MIN
X-> MINUTES
Y-> LBS-SED/MI

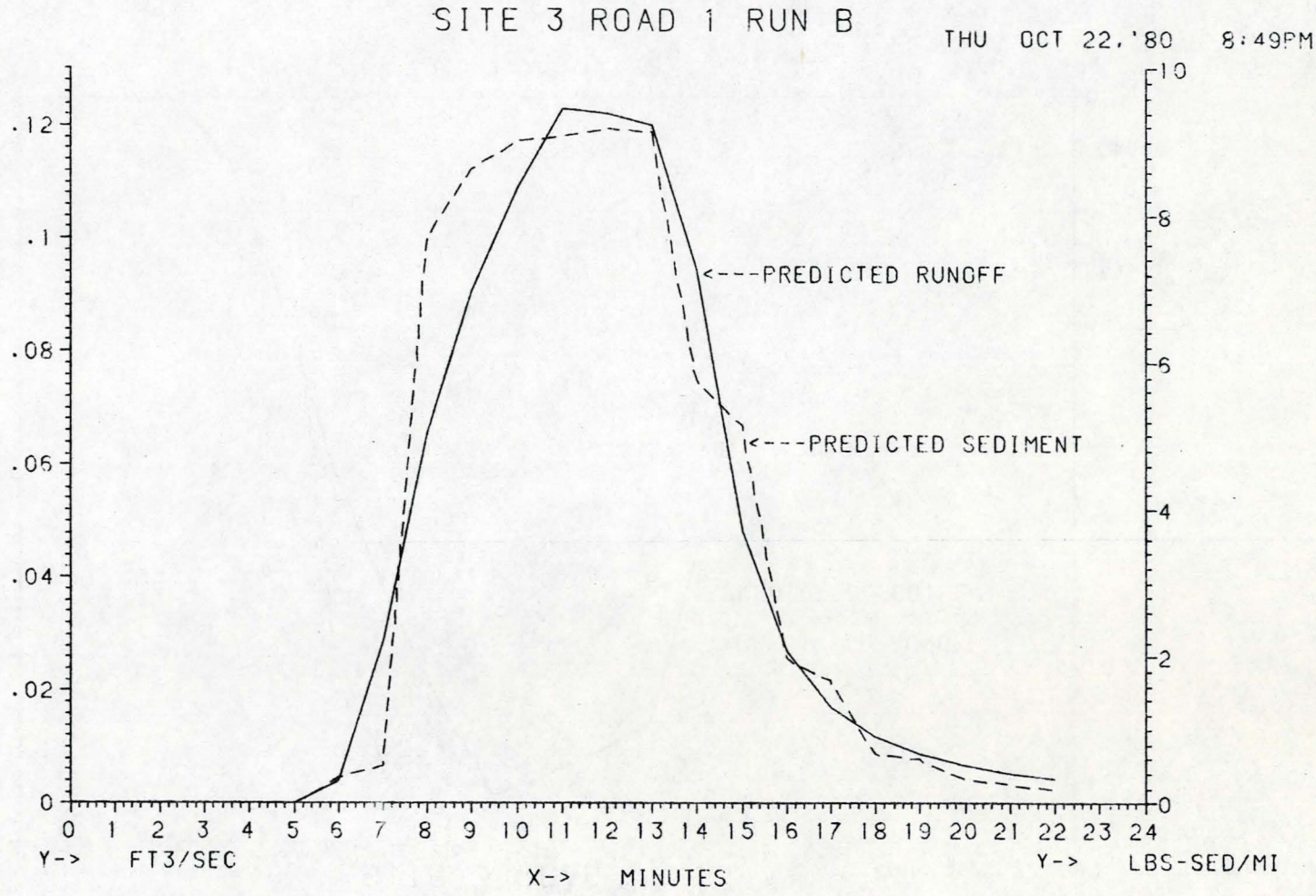

SITE 5 ROAD 2 RUN A
FRI OCT 23, '80 2:00PM
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
<----PREDICTED = 55.6 LBS
<----ACTUAL = 46.8 LBS

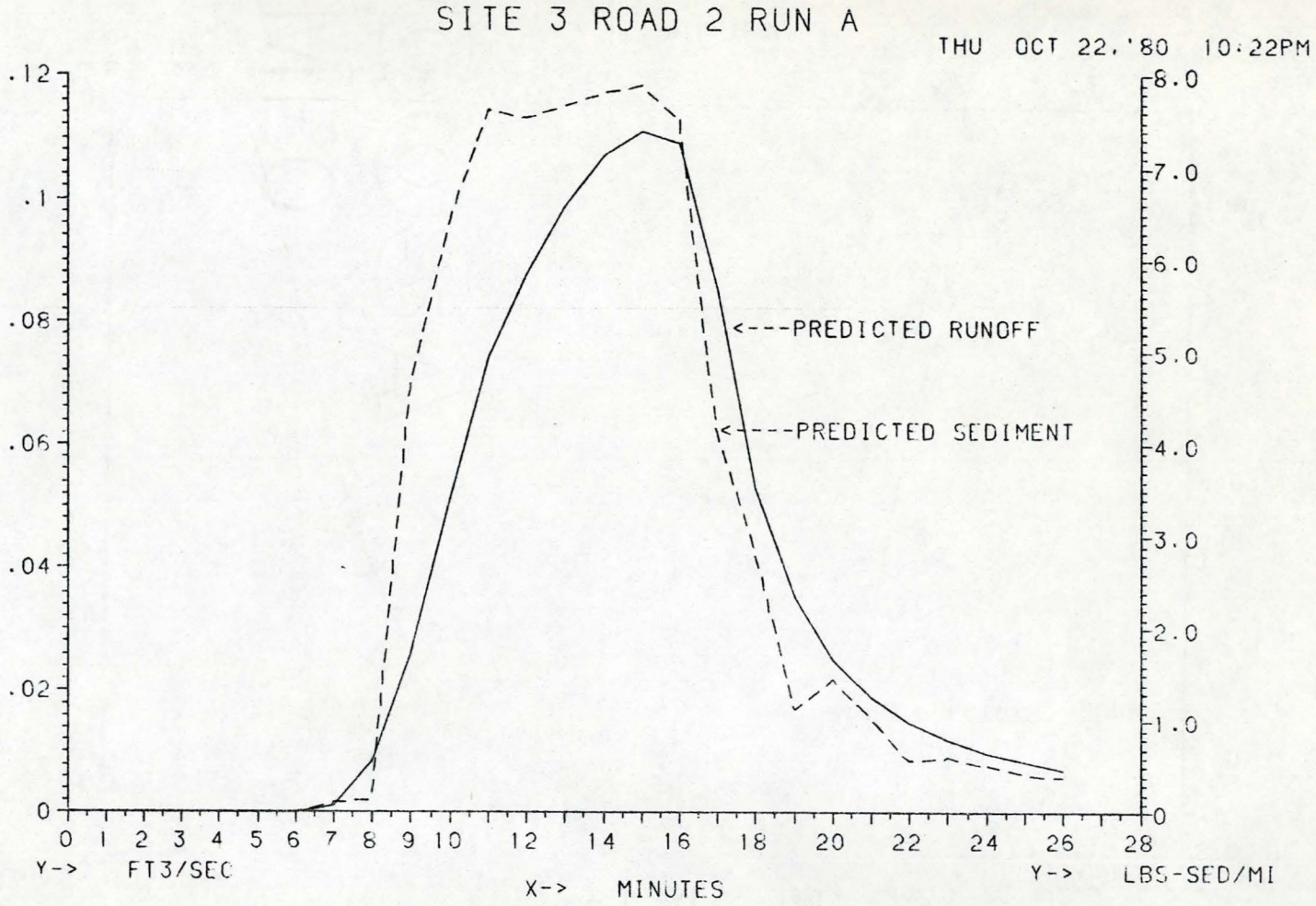

SITE 5 ROAD 3 RUN B
FRI OCT 23, '80 3:25PM
<----PREDICTED = 195.0 LBS
<----ACTUAL = 177.3 LBS
0
2
4
6
8
10
0 5 10 15 20 25 30 35 40 45 50 55
Y-> LBS-SED/MIN
X-> MINUTES
Y-> LBS-SED/MI

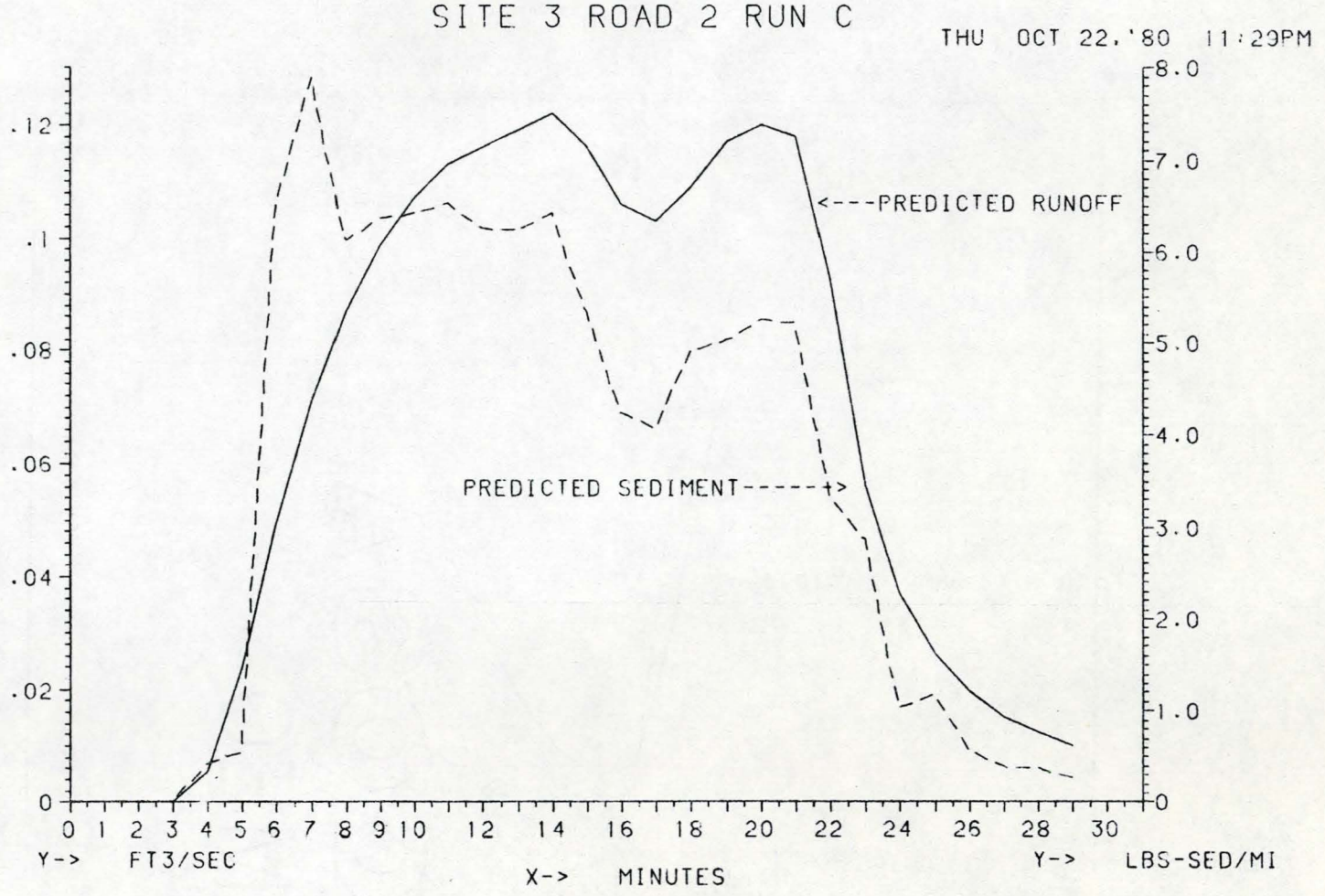

SITE 1 ROAD 1 RUN A
WED OCT 21,'80 10:56PM
<---PREDICTED RUNOFF
<---PREDICTED SEDIMENT
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI

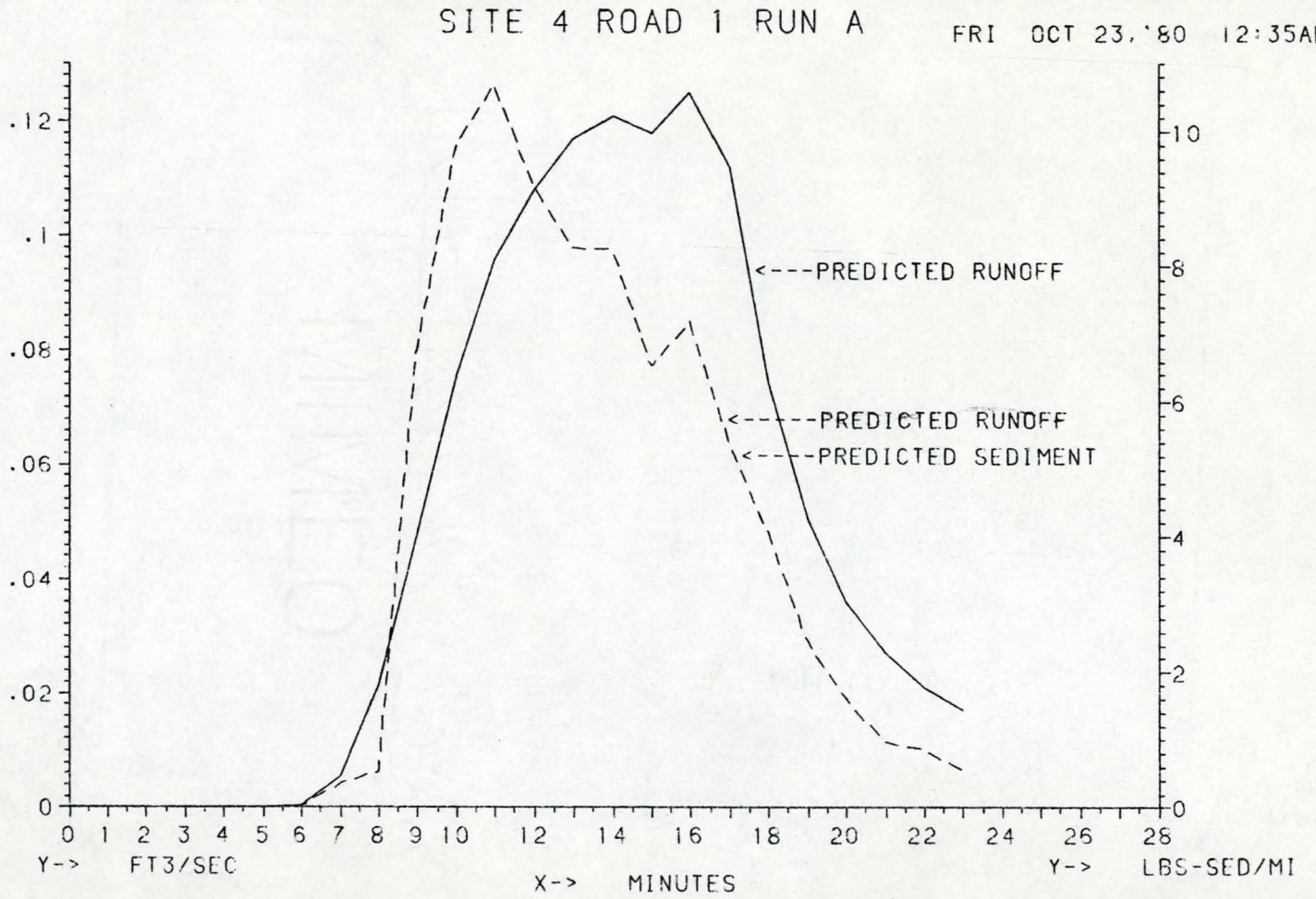

SITE 2 ROAD 2 RUN B
THU OCT 22,'80 12:13AM
.1
.08
.06
.04
.02
0
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
<---PREDICTED RUNOFF
<---PREDICTED SEDIMENT
0 1 2 3 4 5 6 7 8 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI

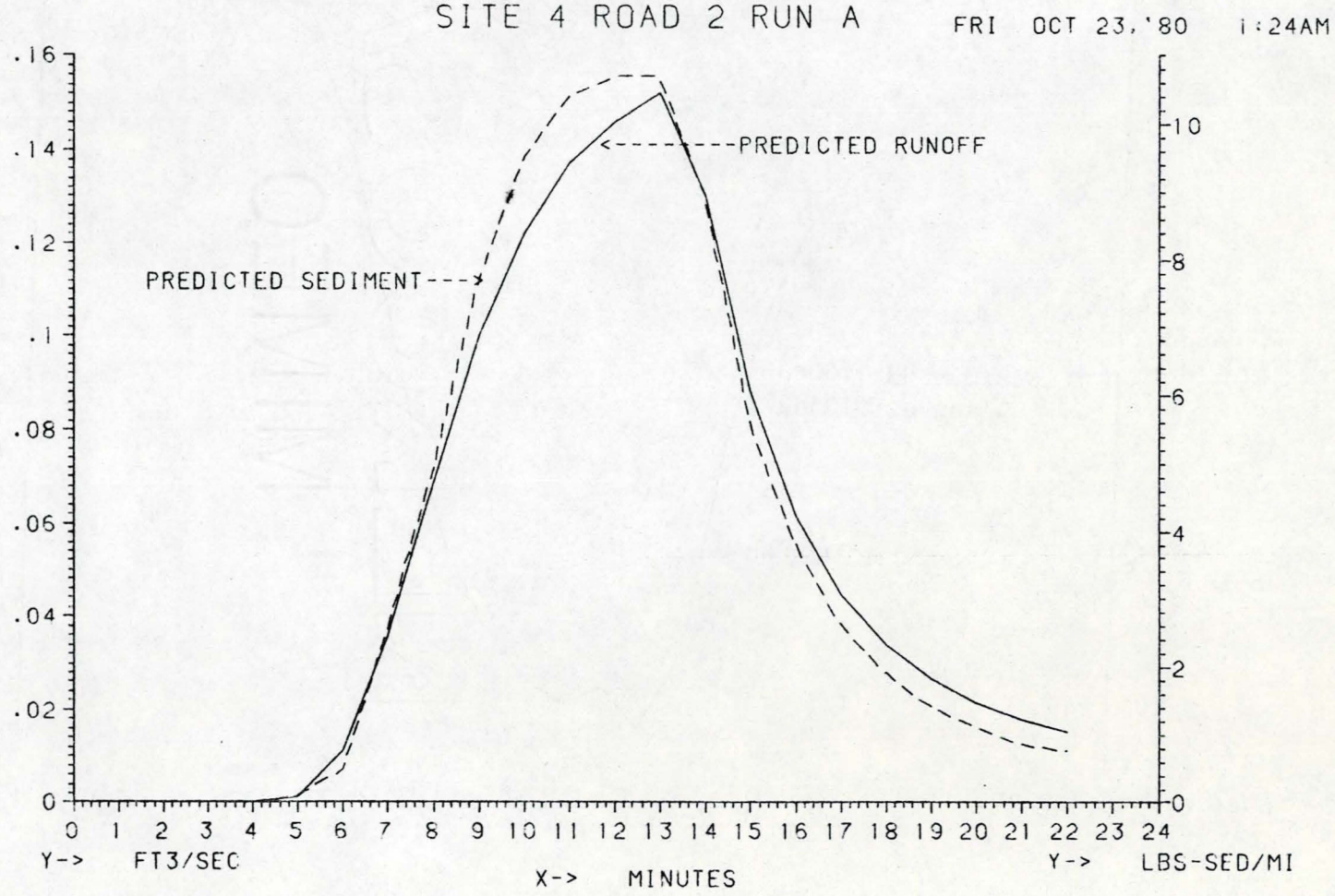

SITE 3 ROAD 1 RUN A
THU OCT 22,'80 1:13AM
.16
.14
.12
.1
.08
.06
.04
.02
0
12
10
8
6
4
2
0
<---PREDICTED RUNOFF
<----PREDICTED SEDIMENT
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI

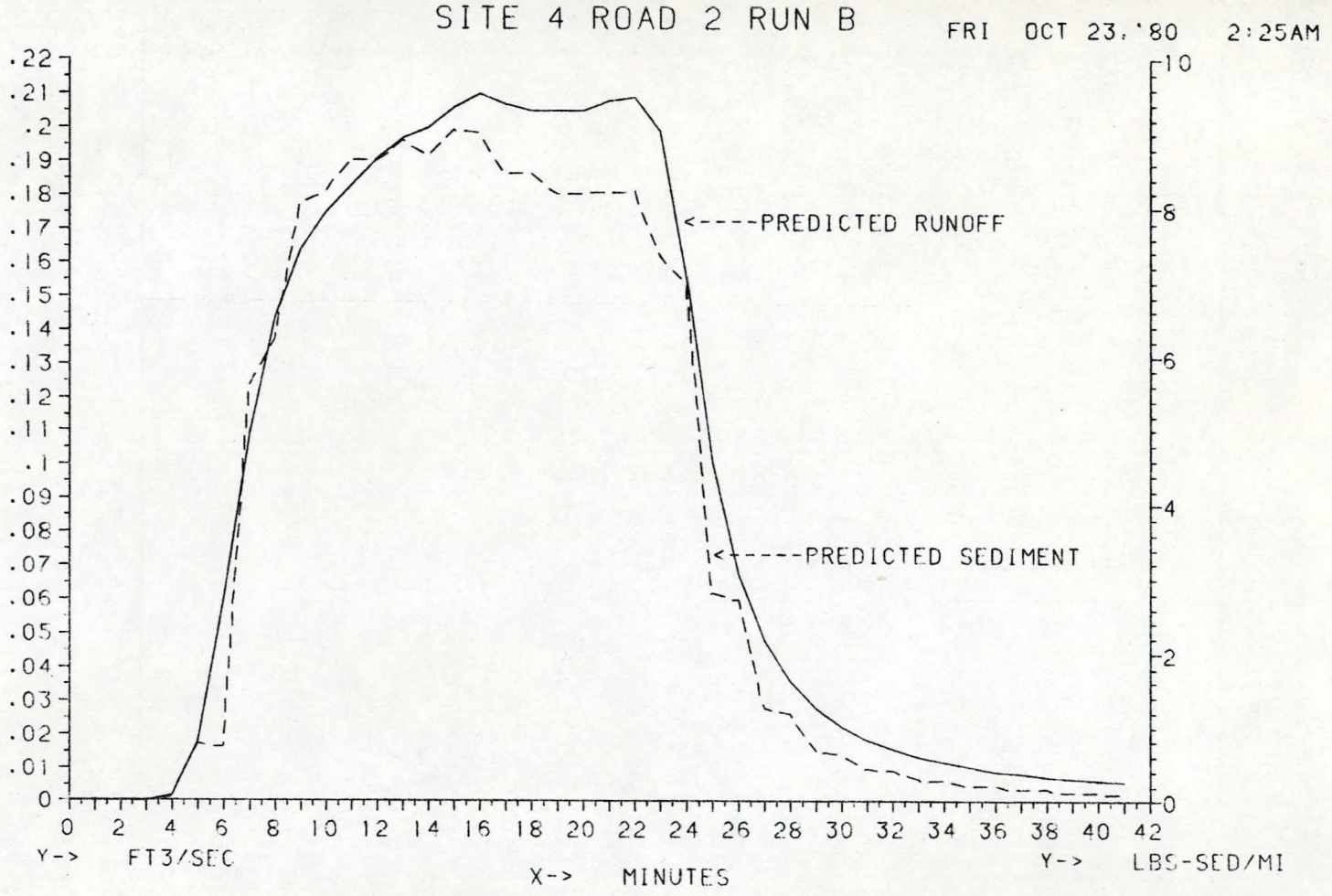

SITE 3 ROAD 1 RUN B
THU OCT 22,'80 8:49PM
<---PREDICTED RUNOFF
<---PREDICTED SEDIMENT
.12
.1
.08
.06
.04
.02
0
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI

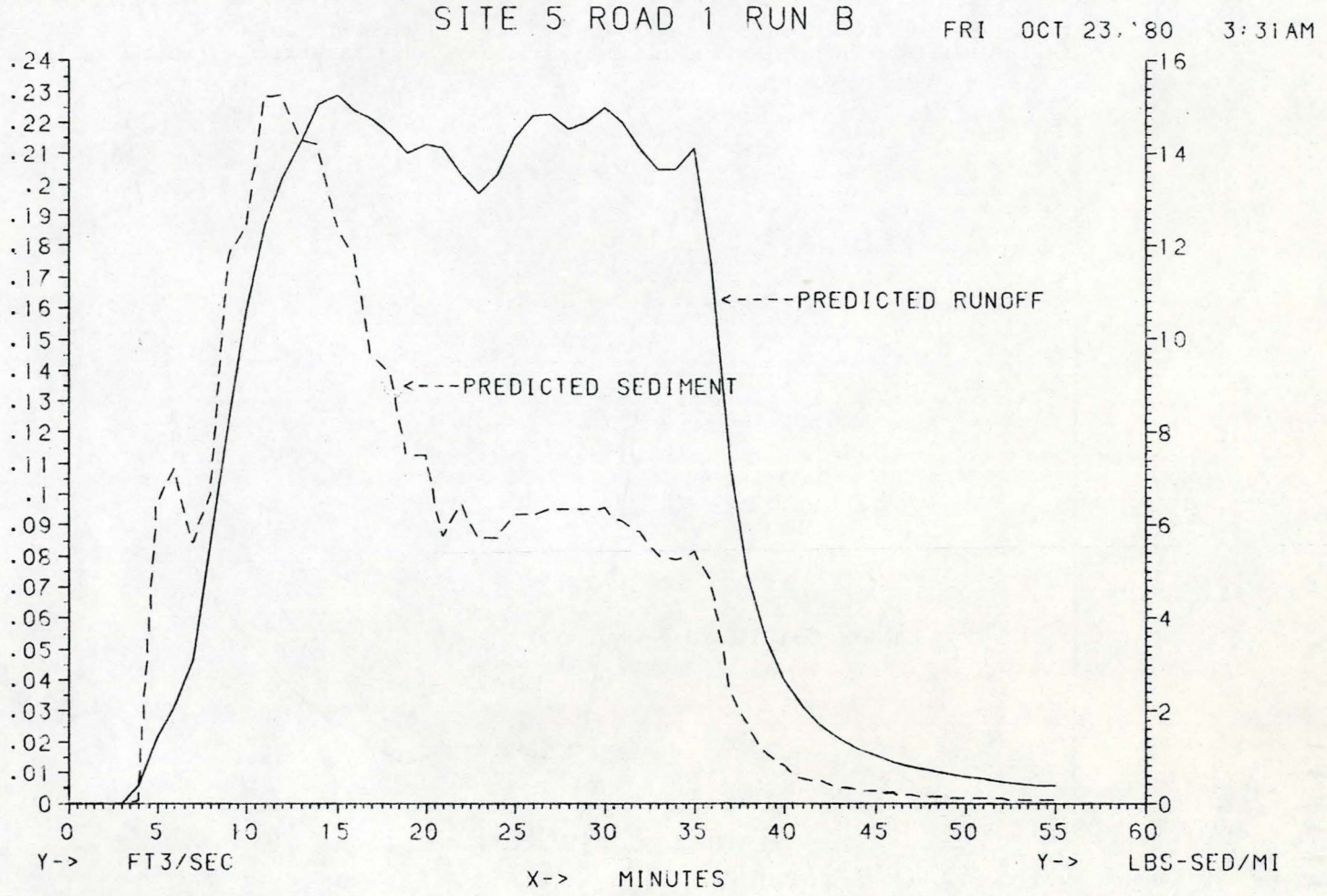

SITE 3 ROAD 2 RUN A
THU OCT 22,'80 10:22PM
.12
.1
.08
.06
.04
.02
0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
<---PREDICTED RUNOFF
<---PREDICTED SEDIMENT
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI

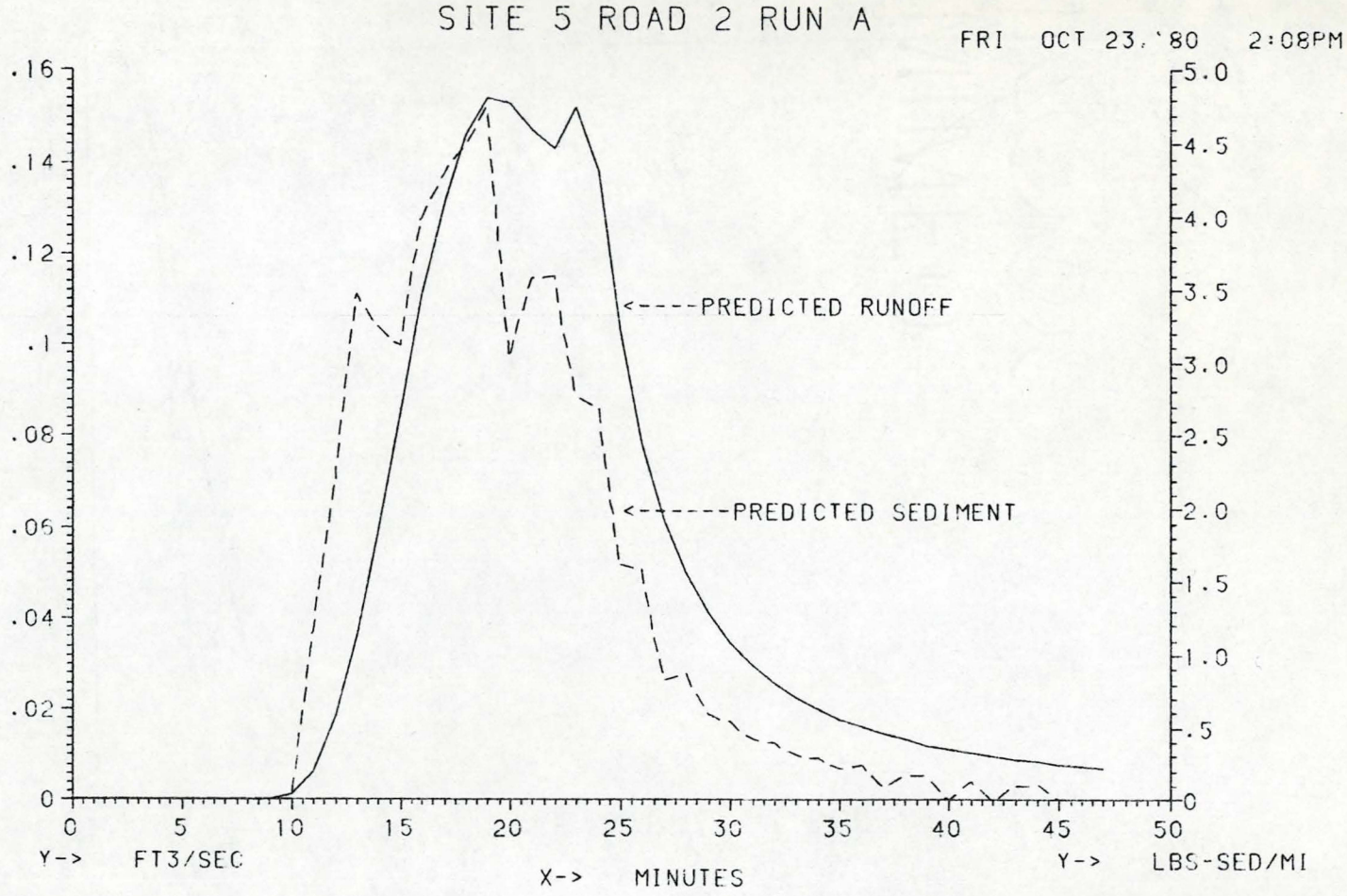

SITE 3 ROAD 2 RUN C
THU OCT 22,'80 11:29PM
<---PREDICTED RUNOFF
PREDICTED SEDIMENT----->
.12
.1
.08
.06
.04
.02
0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28 30
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI

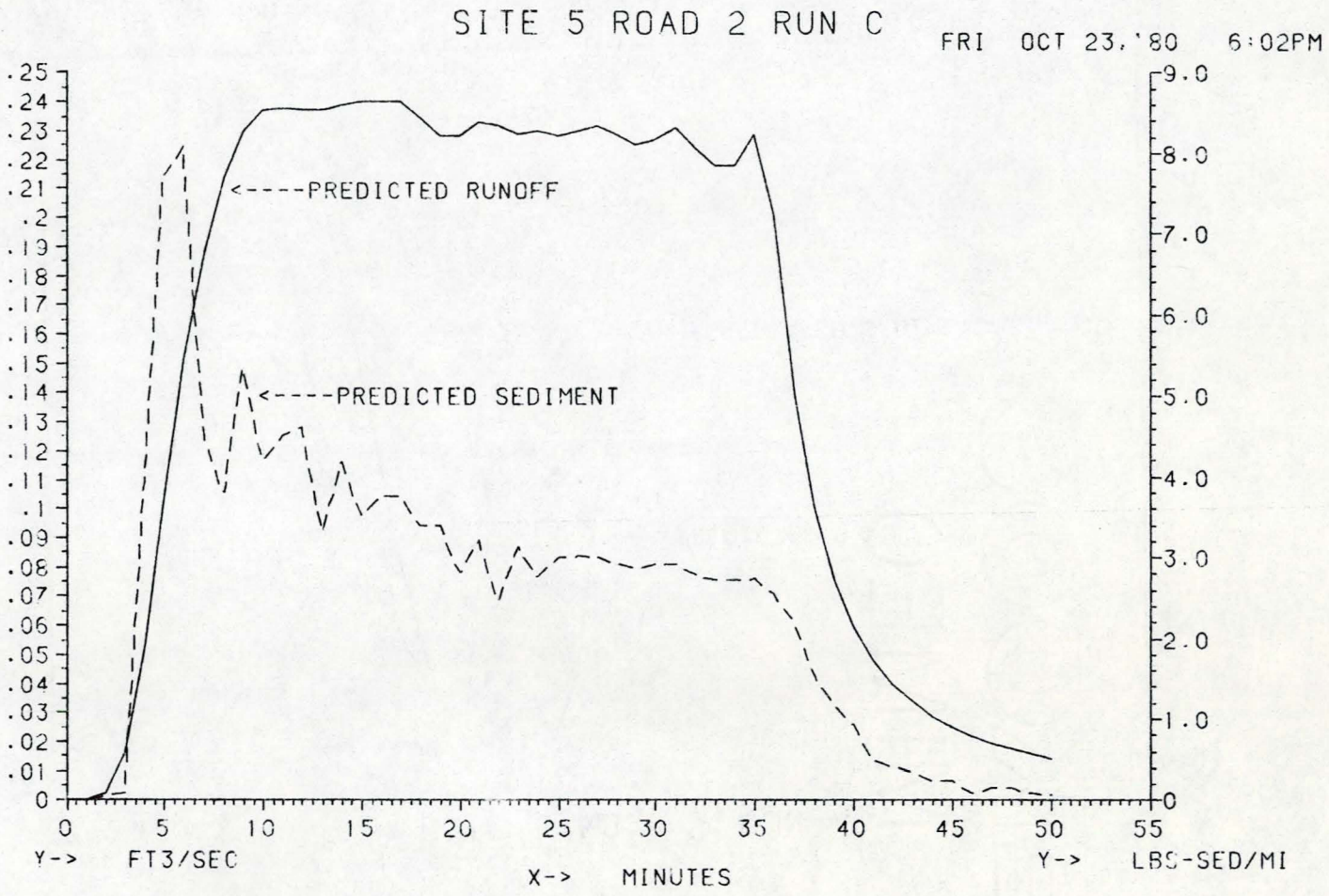

SITE 4 ROAD 1 RUN A
FRI OCT 23, '80 12:35AM
.12
.1
.08
.06
.04
.02
0
10
8
6
4
2
0
<---PREDICTED RUNOFF
<------PREDICTED RUNOFF
<----PREDICTED SEDIMENT
0 1 2 3 4 5 6 7 8 9 10 12 14 16 18 20 22 24 26 28
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI

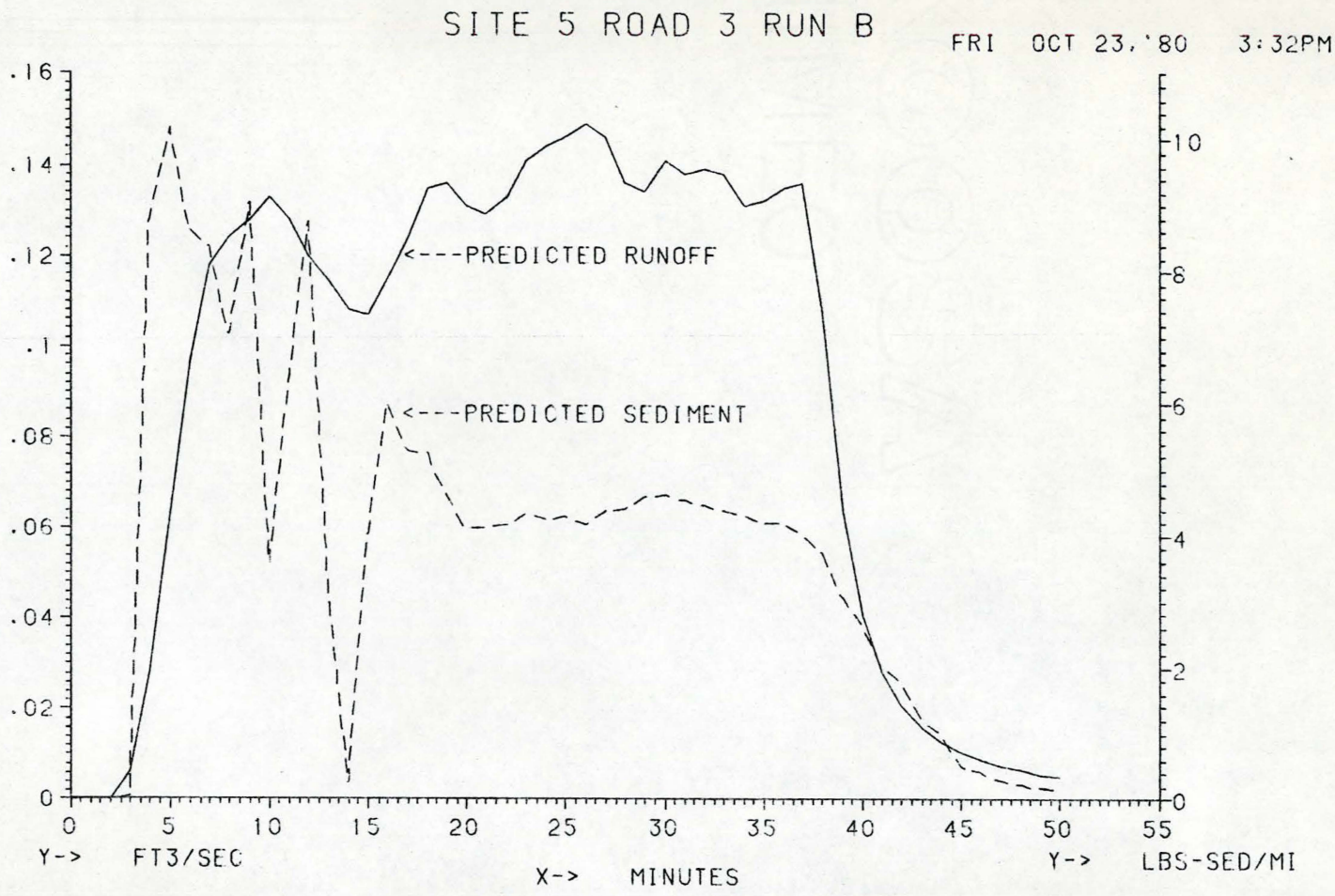

SITE 4 ROAD 2 RUN A
FRI OCT 23,'80 1:24AM
PREDICTED RUNOFF
PREDICTED SEDIMENT
.16
.14
.12
.1
.08
.06
.04
.02
0
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI


SITE 4 ROAD 2 RUN B
FRI OCT 23, '80 2:25AM
<----PREDICTED RUNOFF
<-----PREDICTED SEDIMENT
.22
.21
.2
.19
.18
.17
.16
.15
.14
.13
.12
.11
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
10
8
6
4
2
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI


SITE 5 ROAD 1 RUN B
FRI OCT 23, '80 3:31AM
<----PREDICTED RUNOFF
<---PREDICTED SEDIMENT
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI


SITE 5 ROAD 2 RUN A
FRI OCT 23, '80 2:08PM
.16
.14
.12
.1
.08
.06
.04
.02
0
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
<----PREDICTED RUNOFF
<------PREDICTED SEDIMENT
0 5 10 15 20 25 30 35 40 45 50
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI


SITE 5 ROAD 2 RUN C
FRI OCT 23,'80 6:02PM
<----PREDICTED RUNOFF
<----PREDICTED SEDIMENT
.25
.24
.23
.22
.21
.2
.19
.18
.17
.16
.15
.14
.13
.12
.11
.1
.09
.08
.07
.06
.05
.04
.03
.02
.01
0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0 5 10 15 20 25 30 35 40 45 50 55
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI


SITE 5 ROAD 3 RUN B
FRI OCT 23,'80 3:32PM
<---PREDICTED RUNOFF
<---PREDICTED SEDIMENT
.16
.14
.12
.1
.08
.06
.04
.02
0
10
8
6
4
2
0
0 5 10 15 20 25 30 35 40 45 50 55
Y-> FT3/SEC
X-> MINUTES
Y-> LBS-SED/MI